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MINUTES OF PROCEEDINGS

OF THE

INSTITUTION

OF

CIVIL ENGINEERS;

WITH

ABSTRACTS OF THE DISCUSSIONS.

VOL. XXV.

SESSION 1865-66.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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THE
INSTITUTION
OF
CIVIL ENGINEERS.

SESSION 1865-66.

November 14, 1865.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

No. 1,135.—"The Telegraph to India, and its Extension to Australia and China."[1] By Sir CHARLES TILSTON BRIGHT, M.P., M. Inst. C.E.

IT is scarcely more than twenty years since the opening of the first line of Messrs. Cooke and Wheatstone's electric telegraph, between London and Southampton. Since then, almost every place of any importance in Europe has been included in the rapidly-spreading network of wire; while in India, Calcutta, Bombay, Madras, and all the principal towns, have been connected together. The junction of the European and Indian systems, and the extension of a line from Rangoon to China, and to Australia, by way of Java and Timor, have engaged the attention of telegraphic Engineers for some time past.

The line between Europe and India has now been completed, and a large number of messages are daily sent to, and received from, the chief cities of the Indian Empire. In considering the best mode of constructing a telegraph to India, two routes present themselves for selection, each possessing certain merits and disadvantages. By laying a submarine cable from Malta to Alexandria, and thence by way of the Red Sea and the Arabian coast to Kurrachee, nearly the whole of the line would be submerged, and would thus be free from the risk of interference, at the hands of the natives, to which a land line, passing through Asia Minor, Mesopotamia, and Persia, would be subject.

In 1858, a company was formed, under a guarantee from the Government, and a submarine cable was laid from Suez to Aden and Kurrachee; and there is little doubt, that had the route been carefully surveyed, and had the cable been more substantial and better insulated, the line might have worked well for many years. It should, however, be borne in mind, that at the date when the cable referred to was designed and manufactured, the conditions requisite for carrying out works of the kind had not been so clearly established as they are now, nor had the coating of the conducting wires with insulating materials attained the high degree of excellence which it has since reached.

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[1] The discussion upon this Paper occupied portions of four evenings, but an abstract of the whole is given consecutively.

As the immediate object of this Paper is to describe the operations connected with the line recently established by way of the Persian Gulf, and as the circumstances connected with the non-success of the Red Sea line have been the subject of discussion on previous occasions, the Author alludes to them only so far as is necessary to explain the adoption of the other route.

While the Red Sea line was in course of construction, the Turkish Government were engaged in erecting a line of telegraph, between Constantinople and Bagdad, passing from Scutari, through Angora, Diarbekir, and Mosul. This line, and its extension to the head of the Persian Gulf, had been urged for a long time by Her Majesty's Government, who appreciated the importance of two distinct telegraphs to India. On the failure of the Red Sea line, steps were taken, after a survey by Colonel Goldsmid, to extend the Indian land telegraph in a westerly direction, along the Mekran coast, and for ascertaining the feasibility of erecting land lines through Mesopotamia and Persia, to meet the Mekran telegraph at Gwadur, or Churbar. With the latter object in view, the late Colonel Patrick Stewart, R.E., was sent from India on a special mission to Persia. He arrived in England in the summer of 1862, at the same time that Mr. Latimer Clark, M. Inst. C.E., returned from a careful examination into the state of the cable between Suez, Aden, and Kurrachee. The result of Mr. Clark's investigation showed the impossibility of restoring the Red Sea and Arabian line, and Colonel Stewart reported against the reliability of a land line along the coast of the Persian Gulf.

A submarine cable from the head of the Persian Gulf to Gwadur, the most westerly point to which it was then found practicable to extend the Indian land telegraphs, was therefore determined upon by the Indian Government, in connection with a land line to be erected, with their assistance, by the Turkish Government between Bagdad, Bussorah, and the mouth of the Shat-el-Arab, and with lines to be constructed by the Persians, from the Russian frontier to Ispahan, Teheran, Shiraz, and Bushire, with a cross connecting line, between Bagdad, Khanakain, and Teheran. It was afterwards resolved, in consequence of the workmen on the Mekran land telegraph being molested by the natives, to continue the submarine line, from Gwadur to Kurrachee. Colonel Stewart was appointed to direct the carrying out of this great length of line; the engineering and electrical superintendence of the submarine portion of the work, and the submersion of the cable, being intrusted to the Author, and Mr. Latimer Clark.

To allow of a high speed of working, without any excessive expenditure upon the conductor and insulator, it was determined to divide the line into sections, with a station at Gwadur on the Mekran coast, another near Cape Mussendom on the Arabian coast, at the entrance to the gulf, and a third at Bushire, on the coast of Persia. The soundings and 'bottom' in the Persian Gulf are well known, through the careful surveys of the officers of the Indian navy. The character of the bottom is, however, of so much importance in regard to the permanence of a submarine cable, that a special survey was made by Lieut. A. W. Stiffe, Assoc. Inst. C.E., formerly of the Indian navy. The soundings between Gwadur and Fao are exceedingly favourable for the deposition of a cable, being such as to allow of the cable being laid at a general depth of from 35 fathoms to 60 fathoms, and the bottom being principally composed of sand and soft mud. Between Gwadur and Kurrachee, the bottom is less favourable, being in some places rocky and irregular.

Such being the conditions to be provided for, the core, composed of 225 lbs. of copper, and 275 lbs. of gutta percha per nautical mile, applied in four coatings, with alternate layers of Mr. Chatterton's compound between the coatings, and next to the copper wire, was ordered in November, 1862, from the Gutta Percha Company. In the following month, a contract was entered into with Mr. Henley, of North Woolwich, for applying the outer covering, consisting of a serving of hemp surrounded by twelve galvanized iron wires, each ·180 inch in diameter. The cable, thus covered with iron, was then coated with two layers of a bituminous compound, composed of mineral pitch and silica, with a small proportion of Stockholm tar, applied alternately with two servings of hemp laid in opposite directions; the whole being passed under heavy rollers while in a plastic state, the outer covering being thus pressed between the iron wires, and into a solid mass. By the proper application of such a coating, the outer iron wires of a submarine cable are preserved from oxidation for a long period, and the cost of the materials employed, and of their application is very trifling, compared with the total value of the cable, and its increased durability. For the shore ends, a larger cable was constructed, the outer iron wires being ·300 inch in diameter. A special length of extra heavy shore end, with outer wires ·380 inch in diameter, was made also for use at Bushire.

In the early construction of submarine cables, the conductor was formed of solid wire; but since 1856, when a strand of seven wires was adopted, in the cable laid between Cape Breton Island and Newfoundland, the latter form has been generally used, as there is much less danger of the conductor being broken.

There is, however, the disadvantage attaching to the strand form, that the amount of surface, compared with area, being increased, the retardative effects of induction are proportionately experienced. To obviate this defect, Mr. L. Clark devised, in 1858, a conductor built up of segmental copper wire, and an outer tube was afterwards suggested by Mr. Wilkes. The result of experiments upon this form of conductor, compared with a strand made of the same copper and of the same gauge, showed that the segmental conductor preserved equal mechanical properties, coupled with the best form for electrical requirements.

The respective merits of gutta percha, and of its various combinations, and modes of application, as compared with india rubber, whether pure, masticated, or vulcanized, have been so warmly discussed at this Institution, and elsewhere, that the propriety of adopting gutta percha for use in a warm climate, may be considered, by some, to be questionable. The examination of the Red Sea line, however, demonstrated most distinctly, that there is nothing to prevent the use of gutta percha in a warm climate, if proper precautions are taken; while on the other hand, there is, as yet, no experience of any other insulator which has been shown to be successful on a practical scale, and for a sufficient length of time, to induce confidence in its durability.

The joints made in the insulating material during manufacture, and in the finished core, have always been the subject of considerable anxiety to those engaged in the supervision of submarine telegraphs; as although the loss on a single joint may be so small as hardly to affect the tests obtained upon a considerable length, yet dearly-bought experience has shown, that the defect may contain within it the seeds of a serious fault hereafter. To insure the highest attainable perfection in this important part of the manufacture, a plan was adopted, at the suggestion of Mr. Latimer Clark, which will be readily understood by reference to Plate 1, Fig. 1. A gutta percha trough, about 18 inches long, and 1 foot deep, containing water, is insulated from the ground by four legs of vulcanized india rubber, or preferably, by suspending it from the ceiling by gutta percha cords. The joint under examination is immersed in the water, and a battery of high tension (A) is connected to the copper conducting wire for five minutes, and all the electricity that escapes through the immersed joint during this time passes into the insulated tank of water. To increase the capacity of the tank for storing up electricity, it is connected with an electrical condenser (B), consisting of a great number of talc plates, coated on both sides with tinfoil, and having the same electro-static capacity as 1 mile of the cable. The escaping electricity accumulates in the condenser for the given time, and is then suddenly discharged through a delicate, suspended needle galvanometer (C), and the number of degrees of the deflection furnishes an exact measure of the quantity of electricity passed through the insulator at the joint. In testing the joints in the Persian Gulf cable, by this system, every joint was rejected and cut out whenever it gave less resistance than 40 feet of the core. Newly-made joints were found, almost invariably, to test perfectly, and it was only after at least twenty-four hours' immersion, that a reliable test could be taken. The advantage of this system (which was employed at the Gutta Percha Company's works, and at Mr. Henley's factory) will be apparent from the fact that thirty defective joints were rejected, and replaced.

In testing the conductivity of the conductor, its resistance was taken by means of a Wheatstone's electrical balance. The lowest limit of specific conductivity allowed for the copper was 76, that of pure galvanoplastic copper being taken at 100. An electrician was employed at the copper wire manufactories to see that none below that standard was supplied, and an extra price per pound was paid, pro rata, for all copper having a higher specific conductivity than 81. The mean conductivity of the whole cable was thus raised to 89·14. In many of the older submarine cables, which were laid before this point had received attention, the conductivity was as low as 30 and 40.

Previous to any tests being applied to the core at the Gutta Percha Company's works, the coils were immersed in water at a temperature of 24° centigrade, and the water was steadily maintained at that temperature for at least twenty-four hours. The resistances of the coils, which were in lengths of about 3,000 yards, were carefully recorded and tabulated, and formed an important check to the temperatures shown by the thermometers in the cable tanks, during the sheathing of the core. The coils were then removed to Mr. Reid's pressure cylinder, being still maintained at the temperature of 24° centigrade. The insulation of the coils was next taken with a battery of five hundred Daniell's elements. They were afterwards subjected to a pressure of 600 lbs. to the square inch, and the insulation test was repeated. The lowest standard of insulation admitted was specified to be such, that each nautical mile of cable should give a resistance of 115 millions of Siemens' mercury units, or 109·9 millions of British absolute units. The average resistance of the whole core, at 24° centigrade, was 192·8 millions of British absolute units. The insulation, of course, improved under pressure, the gain being generally about 16 per cent. It was observed also, that irrespective of temperature, all the coils improved greatly by time. Coils, which when first tested gave a certain resistance, would, after six or seven months, give an increased resistance of 100 per cent. and upwards; so that unless the age of a coil be specified, the mere resistance test is, to some extent, fallacious. Each coil was subjected to a time test, by charging the core with a battery of about forty-eight cells, leaving it disconnected for one minute, and then measuring the amount of loss which had been sustained during that time by leakage; the amount of charge remaining was usually from 50 per cent. to 60 per cent. of the original charge. The absolute inductive capacity of each coil was also taken, and recorded.

In the absence of a determinate unit of inductive capacity, or quantity of electricity, condensers were employed, formed of plates of mica, coated on each side with tinfoil, and having a standard capacity equal to that of 1 mile of the Persian Gulf core; these have been found in practice very permanent and extremely convenient for use. The measurements were taken after one minute's electrification, by observing the swing of the suspended needle of a galvanometer; and the extreme variations in the several coils did not exceed 8 per cent. above, or below the average capacity. From these data, when tabulated, it was easy to ascertain the inductive capacity of any portion of the cable, with such accuracy, that in one interruption which occurred during the laying of the cable, from the copper wire having broken within the gutta percha, the distance of the fault which was calculated at 92·33 miles, proved to be actually at the distance of 92·4 miles. Plate 1, Figs. 2 and 3, illustrate this system of testing.

During the manufacture of the core, advantage was taken of the facilities offered at the Gutta Percha Company's works, for trying a series of experiments, as to the effect of temperature upon the conducting power of gutta percha and india rubber. It had long been known, that the resistance of these substances varied greatly with changes of temperature; but the exact law had not been hitherto satisfactorily determined. To endeavour to ascertain this, four coils of the core manufactured for the Persian Gulf cable were lent by the Indian Government. These were immersed in an iron tank, containing about 1,200 gallons of water. The tank was thickly felted on the exterior, and facilities were provided for heating the water uniformly, by steam pipes. The coils were each 1 mile in length, and were first reduced to the temperature of 0° centigrade, by the admixture of ice, and were maintained at this temperature for three days, the water being kept incessantly agitated. The resistances of the copper and gutta percha, and the inductive capacity of the core were then taken. The temperature of the water was next raised gradually, and the measurements were repeated at every 2° up to 38° centigrade. The time occupied in the experiments was thirty-three days, during which nineteen series of observations were taken, the water being kept in constant agitation during the whole period.

From the mean results of these experiments, the following formula has been obtained:—

$$R \times \cdot 8944^{t} = r,$$

where R is the resistance at any given temperature, t the increase in degrees centigrade, ·8944 a constant deduced from experiment, and r the resistance at the higher temperature.

The resistances, when plotted, form a logarithmic curve, as shown in Plate 1, Fig. 4, and for the purpose of comparison, a curve calculated from the above formula is shown in juxtaposition.

The numerical values, as found by experiment, and calculated from the above formula, are given in the following table:—

Temperature (Centigrade).	Resistances obtained by Experiment.	Resistances calculated by Formula.	Temperature (Centigrade).	Resistances obtained by Experiment.	Resistances calculated by Formula.
0°	100·00	100·00	20°	8·43	10·74
2	84·14	80·00	22	6·82	8·59
4	64·66	64·00	24	5·51	6·87
6	47·65	51·20	26	4·47	5·50
8	37·15	40·96	28	3·51	4·40
10	28·97	32·77	30	2·99	3·52
12	23·18	26·22	32	2·48	2·82
14	16·89	20·97	34	1·92	2·26
16	14·37	16·78	36	1·68	1·80
18	11·05	13·42	38	1·43	1·44

It is probable, that the coefficient ·8944 will vary slightly with different samples of gutta percha; and from some tests of the core of the Atlantic cable now under construction, kindly furnished by Mr. Willoughby Smith, it would appear that the formula $R \times 9029 = r$ would apply more nearly to the Atlantic core.

The experiments on temperature were extended to cores of vulcanized india rubber manufactured by Mr. William Hooper. The absolute resistance of this material is well known to be much greater than that of ordinary gutta percha; but its variations of resistance under changes of temperature, are similar in character to those of gutta percha. Between 0° and 38° centigrade, the resistance of gutta percha decreases seventy times, and that of several samples of vulcanized india rubber, from sixty-three to thirty times, depending on the purity of the material. The curve of variations appears to be a logarithmic one, like that of gutta percha, and a similar formula is applicable.

The testing of the core, and the experiments at the Gutta Percha Company's works, were carried out, with every precaution which skill and experience could suggest, by Mr. J. C. Laws, assisted by Mr. F. Lambert, by whom the electrical tests were also taken throughout the laying of the cable.

The coils, after being accepted at the Gutta Percha Company's works, were forwarded to Mr. Henley's factory, where they were deposited in a tank of water, and again tested for insulation. The hempen serving over the core, and the outer galvanized iron wires, were applied in the usual manner, without any novelty in the machinery calling for special remark.

The external protecting coatings of the bituminous compound were laid on by means of an elevator, driven from the closing machine, so that when the machine stopped, the supply of the hot compound ceased. The completed cable was immediately coiled into tanks filled with water, which were under cover, and where it was continually tested. The immediate supervision of this branch of the operations was performed under the Author's directions by Mr. F. C. Webb, Assoc. Inst. C.E., assisted by Messrs. T. Alexander, Assoc. Inst. C.E., J. E. Woods, T. Brasher, T. B. Moseley, Assoc. Inst. C.E., and other members of Messrs. Bright and Clark's staff.

The manufacture of the core, by the Gutta Percha Company, was commenced on the 3rd February, 1863, and was finished by the 23rd October, following: that of the outer covering by Mr. Henley was commenced on the 20th February, and was completed on the 10th November, in the same year.

The following are the lengths and weights of the several forms of cable made:—

	Lengths in Nautical Miles.	Weight in Tons.
Main cable	1,172	4,336
Shore cable	50	500
Extra size shore cable .	12	192
Total . .	1,234	5,028

This quantity of cable was coiled on board the following vessels, between the months of July and November, 1863, each ship taking her departure for Bombay as soon as loaded:—

Names of Ships.	Ships' Tonnage.	Miles of Cable on Board.	Weight of Cable.
Assaye	1,598½	367·98	1399·34
Tweed	1,608	349·39	1328·26
Marian Moore . . .	1,036	174·92	647·20
Kirkham	1,061	187·61	734·20
Cospatrick	1,199	142·10	799·00
Amberwitch	441	12·00	120·00
Total . .	6,943½	1,234·00	5,028·00

The above-named ships, with the exception of the 'Amberwitch,' were sailing vessels, the Government of India being possessed of steamers (formerly belonging to the Indian navy) suitable for towing the sailing vessels during the laying of the cable. Each ship was provided with three iron tanks, a small engine, and a Gwynne's pump for filling and emptying the tanks. Paying-out machinery, consisting of a drum and breaks with the usual stern and leading sheaves, was also fitted. These appliances were similar to those employed on previous occasions, and did not embrace any new, or noteworthy feature.

The 'Amberwitch,' a screw steamer of 441 tons burden, and 70 H.P., was purchased for permanent service on the line, for repairing the cable in case of need, and for carrying stores and changing the staff between the stations. She was fitted with iron tanks for receiving the cable, with paying-out machinery, with an engine and machinery for raising the cable, and with an ample stock of testing apparatus, buoys, chains, grapnels, and all other requirements for repairing submarine cables. The ships were furnished with testing apparatus, and tests were regularly taken on the voyage out, by competent electricians. They arrived in Bombay in the following order:—

Names of Ships.	Electrician in charge.	Date of Arrival.
Marian Moore . . .	Mr. E. Donovan . . .	21st December, 1863.
Kirkham	Mr. E. D. Walker . .	13th January, 1864.
Tweed	Mr. T. B. Moseley . .	5th February, 1864.
Assaye	Mr. J. E. Woods . . .	10th February, 1864.
Cospatrick	Mr. P. Crookes . . .	15th April, 1864.

The 'Assaye' met with bad weather, and it was necessary to lighten her by emptying the tanks. It is satisfactory to record that, although the tanks in one ship were thus emptied for eleven weeks during the voyage out, not the slightest elevation of temperature occurred, owing to the protection from oxidation afforded by the outer bituminous covering. It will be remembered that, in the case of the Malta and Alexandria cable, it was stated[1] by Mr. H. C. Forde, M. Inst. C.E., that the dangerous increase of temperature which took place, when a cable without such protection was left uncovered by water, was the source of considerable anxiety.

During the passage of the cable to Bombay, constant tests were made on board the several vessels, and some interesting records were taken of the currents produced by the action of the earth's magnetism on the coils of cable, at each roll of the vessel. These were most evident in the higher latitudes, became invisible at the equator, and were in the reverse direction in the southern hemisphere. In rough weather, they were sufficiently powerful to interfere seriously with the measurements of the conductivity of the copper wire; but this evil might be at any time obviated, by coiling one half the cable in a reverse direction to the other half.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxi., p. 500.

Sufficient cable for the section between Gwadur and Mussendom having arrived at Bombay in the 'Marian Moore' and the 'Kirkham,' these vessels were towed to Gwadur by the 'Zenobia' and 'Semiramis,' two powerful paddle-wheel steamers of the Bombay marine, commanded respectively by Lieuts. Carpendale and Crockett, formerly of the Indian navy. On the 3rd February the end of the cable was landed from the 'Kirkham,' with the aid of the gun-boat 'Clyde' (Lieut. Hewett), and of the paddle-box boats of the 'Zenobia.' At 8·0 p.m. on the following day the Author commenced laying the cable from the 'Kirkham,' in tow of the 'Zenobia,' towards Mussendom; the screw steamer 'Coromandel,' commanded by Lieut. Carew, with Colonel Stewart on board, piloting the course. On the morning of the 6th, having laid all the cable from the 'Kirkham,' she was anchored in lat. 25° 19', long. 59° 9', Ras Mundanny bearing N.W. ¾ W. In the afternoon the 'Marian Moore,' in tow of the 'Semiramis,' was brought to anchor, in a convenient position for passing over the end of the cable for splicing, and for transferring the stores from the 'Kirkham.' On the following day, the laying of the cable was commenced at 4·0 p.m. from the 'Marian Moore,' the 'Kirkham' being sent back to Bombay for discharge in tow of the 'Semiramis.' On the morning of the 8th the ships anchored off Ras Jask until the evening, in order to make the Arabian coast the next morning, by daylight. The following day, at noon, the 'Marian Moore' came to anchor in Malcolm's Inlet, a quarter of a mile from the landing place. The end of the cable was not landed until the 13th, a short land line having been constructed, in the mean time, to a temporary station on the other side of the peninsula. Mr. Newall's cones and rings were employed in each vessel, and everything worked well and smoothly during the laying of the cable, no incident having occurred worthy of special remark.

Except in the cases of an unsuccessful attempt to connect Cagliari with the coast of Africa, in 1855, and of a cable which was lost, between Newfoundland and Prince Edward's Island, in the same year, submarine cables have hitherto been laid from steam vessels. But, although it is convenient to have steam power immediately under control, on board the ship in which the cable is coiled, the Author considers that in some cases, such as the work now described, where the cable is to be laid in a sea rarely subject to disturbance during the season for submergence, and where the depth of water is not great, sailing ships, towed by steam vessels, may be employed with safety, and it will be found that the economy in so doing, when the cable has to be conveyed a great distance to its destination, is very considerable. In this instance no difficulty of any kind was experienced. The steamer towed the cable-ship with two hawsers, and the ships were in constant communication, by a complete system of signalling. During the day, an apparatus, consisting of a lever carrying a white disc in front of a black board, was placed at the stern of the steamer, and on the forecastle of the cable-ship. By night, a signal lantern, with an obscuring disc, was used. Telegraph signallers on board each vessel were always on duty, using the dot and dash telegraphic alphabet with the apparatus. By this means, every requisite message was rapidly sent to the towing steamer, and the instructions conveyed were so promptly despatched and acted upon, that no inconvenience whatever was felt from the separation of the vessels.

The electrical observations made on board ship during the paying-out of the cable, were numerous, and required thirty-four columns of figures at each set of measurements. They comprised a test for conductivity and insulation, and the power of communication with the main land for five minutes, every quarter of an hour. The admirable marine galvanometer of Professor William Thomson, F.R.S., was used. This consisted of a doubly suspended needle and coil, with a small mirror and reflecting apparatus. The instrument was enclosed in a massive case of wrought iron, to reduce the effect of the earth's magnetism.

After the completion of the Gwadur and Mussendom section, some delay arose, owing to the other ships not having arrived. The time was occupied in establishing a station upon an island in Elphinstone Inlet, and in coaling the steamers at Bassadore and Muscat, where supplies of coal had been provided by the Government of Bombay, to meet the requirements of the expedition.

The 'Tweed' and 'Assaye' arrived in Elphinstone Inlet on the 12th and 13th March respectively; and on the afternoon of the 18th of the same month, the laying of the cable towards Bushire was commenced. Nothing that requires special remark occurred during the laying of this section, nor in the completion of the other portions of the line. The distance run, the length of cable laid, and the depths of the several sections, are given in the following table:—

Section.	Distance Run in Nautical Miles	Cable Laid in Nautical Miles.	Mean Depth in Fathoms.	Greatest Depth in Fathoms.	Date of Completion.
Gwadur-Mussendom	315·50	357·34	47	122	Feb. 14, 1864.
Mussendom-Bushire	379·25	392·65	35	58	March 25, 1864.
Bushire-Fao . . .	149·00	152·20	20	26	April 5, 1864.
Gwadur-Kurrachee .	241·00	246·00	20	64	May 15, 1864.
Total . .	1114·75	1148·19	..	..	..

An additional length of 18 miles of cable was added to the Gwadur-Kurrachee section, to bring the line to Minora point, near Kurrachee, in place of Cape Möaree (the original landing place), making the length of that section 264 miles, and the total length of cable laid 1,176 miles.

The line in the Gulf, and across its entrance, is laid upon an exceedingly regular bottom; upon a portion of the Mekran coast, and especially between Gwadur and Kurrachee, the bottom is by no means so good, being in some places rocky and very irregular. To have laid the line more to the south, would have imperilled the successful accomplishment of repairs, in case of need hereafter; but the cable is no doubt subject to risk upon this section, and has already required repair in shallow water, from chafing on the rocks during the S.W. monsoon in the year 1864.

The temperature of the sea, at the upper end of the Persian Gulf, was, when the cable was laid, 21° centigrade at the surface, and 17° at the bottom; at the entrance to the Gulf, it was 23° at the surface, and 21·5° at the bottom; and near Kurrachee, 26° at the surface, and 24·2° at the bottom.

The following are the insulation tests taken after immersion:—

Section.	Temperature at the Bottom.	Resistance per Nautical Mile.	
		Siemens' Units.	British Absolute Units.
Gwadur-Mussendom . .	22° centigrade	358 millions	342 millions
Mussendom-Bushire . .	21 ,,	390 ,,	373 ,,
Bushire-Fao	17 ,,	601 ,,	575 ,,
Gwadur-Kurrachee . .	24 ,,	280 ,,	268 ,,

It will be observed that, there is apparently a great difference between the insulation of the several sections. By reducing the resistances, however, to the same temperature, they will be found to be remarkably uniform. Thus the comparative resistances at 24°

centigrade, the temperature of the Gwadur-Kurrachee section, and also that at which the tests were taken during the manufacture of the core, are—

Section.	Resistance per Nautical Mile.	
	Siemens' Units.	British Absolute Units.
Gwadur-Mussendom . .	286 millions	274 millions
Mussendom-Bushire . .	279 ,,	267 ,,
Bushire-Fao	276 ,,	264 ,,
Gwadur-Kurrachee . .	280 ,,	268 ,,

If the cable, offering a mean resistance of 280 millions of Siemens' units per nautical mile, had been laid in sufficiently deep water to reach the unvarying temperature of 39·5° Fahrenheit, or about 4° centigrade, which is met with at a depth of 1,500 fathoms, the resistance would have increased, by the difference of temperature, to about 2,600 millions of units per nautical mile, with the additional increase due to pressure, which is about 16 per cent., for every 200 fathoms.

From the date of the completion of the submarine line in April, 1864, it has been regularly worked by an efficient staff of station superintendents and signallers, selected from the service of the telegraph companies in this country. Mr. Walton, who had charge previously of the Mekran Coast Telegraph, is the chief superintendent. Instruments of the most modern construction are employed at each station, supplied by Messrs. Siemens and Halske, who also provided the iron posts and insulators, used over part of the Turkish and Persian land lines.

It was expected that the Turkish land line, between Bagdad and the head of the Gulf, would have been completed simultaneously with the submersion of the Persian Gulf cable. In this, however, much disappointment was experienced, notwithstanding the indefatigable exertions of Colonel Kemball, C.B., H.M. Resident at Bagdad. The line was completed with the aid of Mr. T. H. Greener, southwards, from Bagdad to Hillah, and thence to Diwanyeh, and northwards, from Fao to Korneh, where the Tigris and Euphrates meeting, form the Shat-el-Arab; but the Montefic tribe of Arabs being in revolt against the Turkish Government, the completion of the line was delayed until the commencement of the year 1865. It was not until the end of February, that arrangements had been so far organized as to allow of the line to India being opened for the transmission of public messages, when a telegram was received in London from Kurrachee, in eight hours and a half. This was speedily followed by numerous commercial messages to and fro; and the line is now in daily operation, carrying a large traffic between India and Europe.

In the working of the Turkish line there is, however, much room for improvement, which it is hoped the importance of the traffic will induce. Before long, the opening of the Persian line of telegraph from Teheran to Ispahan, Shiraz, and Bushire, with the connecting line from Bagdad, by Khanakain, to Teheran, will afford an additional route by which the Persian Gulf cable may be reached, passing through Russia by way of Tiflis and Erivan, and the competition of the two lines will no doubt materially improve the service.

These extensive lines have been finished under the superintendence of Major J. U. Champain, R.E., assisted by Lieutenants Pearson and St. John, R.E., and a few selected non-commissioned officers and men. The energy and perseverance with which this arduous duty has been performed, can be best appreciated by those who have worked in an Oriental country, with all the difficulties of absence of land carriage and labour, coupled with every form of official apathy and obstructiveness.

The extension of the telegraph to Australia must speedily follow the successful establishment of electrical communication between India and Europe. At present, the Indian telegraphs are constructed as far to the eastward as Rangoon; the distance thence to Singapore is about the same as that of the Persian Gulf line, and a route with a favourable bottom can be selected for a cable. Between Penang and Singapore it would be desirable to lay a heavier cable than in the northern portions of the line.

The feasibility of establishing a land line down the Malay Peninsula demands consideration, before determining upon the adoption of the sea route. There are no insurmountable physical difficulties, as regards either the country, or its inhabitants, to prevent the erection and maintenance of a land line. There are, however, no roads, except mere bridle-paths, to the south of Tavoy, and a large expense must be incurred in clearing the jungle.

The cost of a submarine cable in Europe compared with a land line, is very great; but the cost of a land line in uncivilized countries, without facilities for the conveyance of stores and workmen, is considerably increased, while the cost of maintenance, and the chances of interruption and delay, in re-establishing communication, are also greater. The regularity of the working of a properly-constructed cable would, in the Author's opinion, soon compensate for the additional outlay involved in the adoption of the sea route, by which also the communication could be more speedily effected.

Between Singapore and Hong Kong, a cable can be readily carried in shallow water, touching at Saigon; or the connection with China may be made by crossing the peninsula with a land line at Mergui, and carrying a cable across the Gulf of Siam. A further portion of the route might be carried by land, by way of Bangkok, and Cochin China; but the Author is of opinion that although a branch, or a loop line, might be taken by land in this direction, the main line, upon which the regularity of the Chinese traffic would depend, should be submarine.

It has been proposed to take a land line of telegraph from Rangoon, through Birmah and Western China; and the arguments urged in favour of this route by its projector, Captain Sprye, are very strong. The Russian Government is also gradually extending the telegraphs to the Chinese frontier, with the intention of ultimately connecting Pekin with the Russian system.

To discuss the relative geographical and commercial features of these projects would exceed the limits of this Paper; but the Author considers, that at present the best, most reliable, and most speedy plan for connecting China to India by telegraph, is by a submarine cable.

Proceeding southwards from Singapore towards Australia, the first section, from Singapore to Banca Island and Java, can be taken in shallow water. A cable laid in 1858 from Singapore to Batavia failed soon after being laid; but the cable was a very light one, and unsuited to the bottom. By selecting the route to be followed, and laying a properly-constructed cable, there would be no difficulty in maintaining permanent communication between these points. A land line of telegraph has already been constructed, by the Dutch Government, throughout Java, and a cable may be taken from the south-eastern extremity of that island to Timor, terminating at a station to be established at Coupang. From Timor to the north coast of Australia, a submarine line can also be laid in shallow water, with the exception of a short distance to the south of this island, where the depth is not known, no positive soundings having been yet taken. The telegraph is rapidly extending northwards, from Brisbane towards the Gulf of Carpentaria, and the whole of the intermediate country is being quickly occupied by settlers.

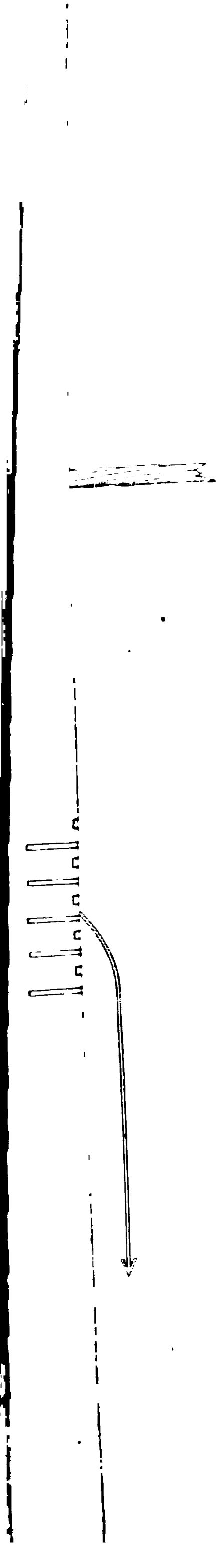
The Author cannot conclude without expressing his deep regret, that Colonel Stewart did not survive to witness the completion of his labours, the opening of the Indo-European line, to the accomplishment of which he so largely contributed by his energy and perseverance. By his death the country has lost an accomplished and fearless officer, unsurpassed in zealous devotion to his duties, and rarely equalled in administrative capacity.

The communication is accompanied by a series of diagrams, from which Plate 1 has been compiled.

Sir CHARLES BRIGHT said, that since the Paper was written, in May, 1865, the line had been in working order, with the exception of sixteen days, and it had been so far commercially successful, that the receipts had been at the rate of about £8,000 per month, or nearly £100,000 per annum, on a capital of £400,000. These receipts would have been greater if the line had been worked for its whole length in the way it ought to have been, but such was not the case. He had referred, in the Paper, to the defective working of the Turkish line, and the administration of that section, so far from being improved, was positively worse than at first, as messages now occupied eight days or nine days, which ought to be transmitted in as many hours. The service as far as Belgrade was not badly conducted, but from thence to Constantinople and Bussora nothing could be worse. The Persian Gulf line proper was worked well, considering the climate and the number of repetitions. He found, from the returns at the India Office, that the average time occupied by the messages from Kurrachee to Fao, at the head of the Persian Gulf, was about three hours, while over the other portions of the line in many cases the transmission, as he had previously stated, took from eight days to nine days. It would thus be seen, that the complaints of the working of the Indian line were not without foundation. Again, in some instances, a message was as long in being sent from Bombay to Kurrachee, as from Kurrachee to London, a delay of several days frequently occurring over a few hundred miles of land line. When in Bombay, in 1863, he met a member of the Institution, who was waiting for a reply to a message which he had sent to Madras seven days previously. The following extract from a letter, dated 17th September, 1862, addressed by the Chairman of the Chamber of Commerce at Kurrachee to the Commissioner in Scinde, referring to the line from Bombay to Kurrachee, would show that that was not the only ground of complaint:—

"The line from Bombay to Kurrachee has always been an uncertain one, but of late the evil has so increased as to be productive of the most serious inconvenience to the public, and an interrupted state of the line is becoming the rule instead of the exception. As illustrating the inconvenience the public are put to, I may mention the present painful uncertainty with regard to the mail steamer 'Koringa,' now some days overdue from Bombay, caused by the impossibility of communicating by telegraph with that port. The evil is intensified, moreover, by circumstances which the Chamber desire to take this opportunity of bringing to your notice, in the hope that a vigorous investigation may be made into the working of the telegraph.

"In the first place, it has been several times recently remarked, that interruptions are reported on the line just after the arrival of the mail-steamers in Bombay, or on the receipt there of telegraphic advices *viâ* Galle. The consequence is, that messages for the press, and private advices containing important intelligence, do not come to hand for some



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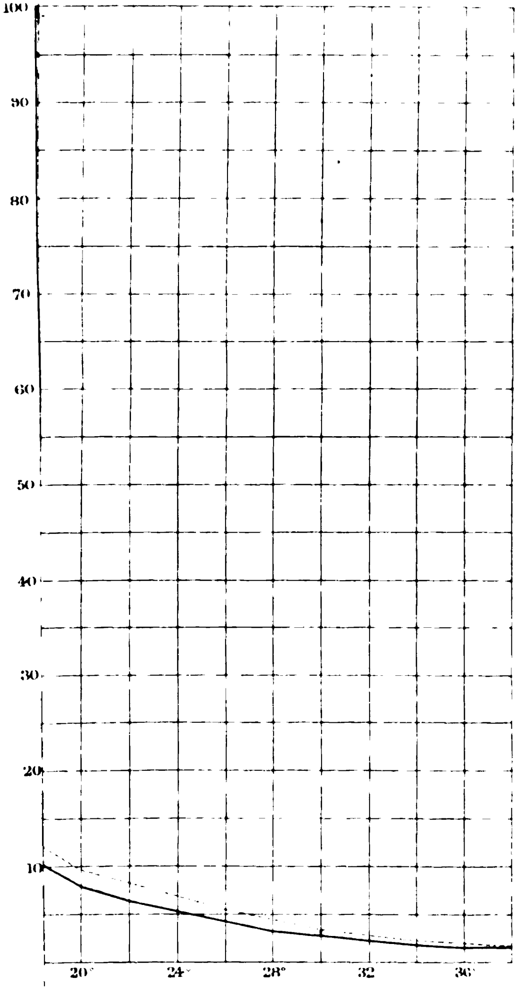

A PERCHA CORE OF THE PERSIAN GULF CABLE.
URES OF 0° & 38° CENTIGRADE.

KELL BROS LITHRS CASTLE ST HOLBORN.

LIBRARY
OF THE
UNIVERSITY
OF
CALIFORNIA

days afterwards. In the second place, this interruption does not prevent full and detailed information reaching the native community, who contrive, in some manner, to become conversant with the state of the English market in spite of the interruption. There are only two ways of explaining this circumstance, either that native messages obtain an undue preference, and are pushed forward before Chamber of Commerce and press messages, or else that the line is cut, and the messages read off by persons employed by the native merchants.

"You are doubtless aware that precisely the same complaint has been made by the Chamber of Commerce in Bombay; and there is a settled conviction in the minds of the public, that the evil complained of is the result of an organised system of criminal practices, which can only be exposed and rooted out by a searching and rigorous inquiry on the part of the Government."

That state of things was not much improved at the present time. It was of little use to have a good line of 1,200 miles in the middle of two defective systems; and yet, under the circumstances that had been described, the line was paying the Government 20 per cent. upon the outlay.

He had referred to the experimental trials made upon certain lengths of wire coated with india rubber at different degrees of temperature, as compared with gutta percha. A number of lengths of different kinds of core were sent out by the Government for experiment, and the results obtained with the cable supplied by Mr. Hooper were so satisfactory, that the Government of India had ordered another length of 50 miles for that country. That line was now being made, and the results of the testing were such as to afford encouragement for the belief, that at length a good india rubber core, of high insulation, and capable of withstanding the temperature of any climate, had been obtained. As regarded resistances, while the gutta percha core of the Persian Gulf cable only gave from 170 millions to 200 millions of Siemens' units, the average of thirty-three coils of Mr. Hooper's core, now being manufactured under the superintendence of Mr. Latimer Clark, gave a resistance of 8,128 millions of units at a corresponding temperature. There was, of course, the question of durability to be determined, in regard to this, as well as every new manufacture. He had preserved a specimen of this system of insulation since 1859, and he could detect no change whatever in the material. Moreover, specimens of this cable, which had been experimented upon three years ago, were then deposited in a corner of a warehouse, and had since been removed and put under water, showed at the present time a resistance of 8,376 millions of units, as against 5,418 millions of units at the former period, thus indicating that the cable had not become deteriorated after being subjected to the worst kind of treatment, viz., taking it out of the water and leaving it for a long time exposed to the air. With this form of core there was a good prospect of getting superior insulation and better properties as regarded induction. He wished to add that he had no pecuniary interest whatever, either in gutta percha, india rubber, or any other insulator, and that his sole object was to get the best material.

Mr. C. W. Siemens said, the Author had well described the construction of this cable, and some of the difficulties that had been met with in submerging and working it. With regard to the difficulties in the transmission of messages through Turkey and India, it was to be borne in mind that in India, nearly all the lines were made without insulators in the first instance, the line-wires having been suspended from wooden cross pieces fastened to the poles, and afterwards insulators of unsuitable and untried forms were used. No wonder, then, that the lines should be in a bad condition, independently of the other reason given—that the staff was wholly inadequate to the business. He considered that, electrically, the Persian Gulf cable was well adapted to its purpose, being in accordance with the proportions he had recommended, when the question was referred to him by the Indian Government in the first instance. Messages could be sent through it, with the instruments used, at almost any speed at which the clerks were capable of working the keys. He did not think the form of the conductor was, however, one that would be generally adopted hereafter. It was certainly very tempting, to adopt a conductor of several wires, with the guarantee of the tenacity of the different members of the whole, and at the same time presenting the least development of surface for conductivity; but he believed there were risks connected with it, particularly as regarded the joints, which had to be made the same as in a solid wire. The outer covering seemed to have succeeded perfectly. He had had some fear lest the application of the hot material on the outside of the cable might, at a moment when perhaps the machine was badly attended to, cause the more fusible gutta percha to melt; but that did not appear to have been the case. His experience rather went to prove that a cable would work (provided it had been manufactured under proper superintendence) exactly as long as the outer covering lasted; therefore every effort should be concentrated on making an outer covering which should be durable for many years. With regard to shallow sea cables, there was a remedy, though perhaps a coarse one, by using large galvanized wires. The covering which Messrs. Bright and Clark had applied to the Persian Gulf cable was another solution; but such an outer covering could not be used for deep seas, and he thought the most important question of the present day, in regard to deep sea telegraphs, was what outer covering would combine lightness with permanent strength? The solution which Mr. Siemens had worked out, was a flexible armour of copper or iron, which had already been brought before the Institution.[1] He was gratified at hearing the high eulogium which the Author had passed upon the late Colonel Patrick Stewart. Too high praise could not be bestowed upon that most able and disinterested officer, who had fallen a victim to his anxiety in carrying out this great work.

Captain **Douglas Galton**, R.E., fully concurred in the high eulogium paid to his friend the late Colonel Stewart. With respect to the line to Kurrachee, he was consulted by Colonel Stewart in the original arrangements, and he had watched its progress with attention and interest. He was glad to hear a satisfactory account of its present working. He certainly had shared in the fear, that the outer bituminous covering, applied when in a heated state, might perhaps have injured the gutta percha, but such had not been the result. With respect to deep sea lines, he did not feel much alarm as to the outer covering not remaining perfect for a series of years after the line had been laid. He conceived that lines laid in deep seas, if they survived the first year or so after submersion, would probably go on for several years; that, however, was a question on which no regular law could be laid down, inasmuch as a deep sea cable, laid upon a bottom like that of the Mediterranean, would probably differ very much from one laid in the Atlantic.

Mr. W. H. **Preece** said, the Author had stated that the receipts on the Persian Gulf line were highly remunerative, and from his personal knowledge he was aware that the number of messages passed daily through the distance which this line traversed was very great. Delays in transmission arose from various causes. The first arose from the peculiar manner in which the lines were worked in India; but some improvement might be expected in that respect, because the present Governor-General—Sir John Lawrence—had acquired some knowledge of telegraphic operations, through his connection, as a Director, with the Electric and International Telegraph Company, and Mr. Preece believed that some active steps would be taken by his Excellency to improve the working of these lines. The root of the evil, no doubt, was in the peculiar constitution of the staff, but it was also largely due, he believed, to the manner in which the Indian lines themselves were constructed. The work through the cable was conducted as well, almost, as it could be, but there was a long length of line from Bagdad to England, one length through Persia and Russia, and another through Asia Minor into Europe. There was a well-organized and well-constructed line of telegraph between Malta and Alexandria. Looking at the map, it struck him that between Bagdad and Beyrout there was a convenient route for a new line of telegraph, and, comparing the distance with that of the Persian Gulf, it did not seem to be more than 400 miles or 500 miles. With the present knowledge of, and experience in telegraphy, whether the districts through which a line passed were mountainous, or desert, populated or not, means could be devised for carrying a line through those countries, so as to be secure from the depredations of the natives. In constructing a line through the desert timber-posts could be dispensed with, and brick pillars could be used, at distances of about a quarter of a mile apart, and of such a height as to put the wires out of the reach of the Arabs.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxi. p. 529.

Mr. ACTON AYRTON, M.P., said, not having been in India for the last year or two, he could say nothing from personal observation on the state of the telegraph in that country at the present moment; but he thought the telegraph system in India afforded a remarkable illustration of the difficulty, if not the impossibility, of the Government effectually carrying out any enterprise of a commercial, or industrial character. It so happened that when this question was first under consideration, he was in Calcutta, and he was desirous of making a proposal that, instead of the Government undertaking the work themselves, they should grant a concession to a company to do it; but Lord Dalhousie, who was then Governor-General, determined that it was essentially an affair of Government to construct the telegraph in India; therefore, instead of the project being carried out by a company in a year, or two, it was carried out by the Government in about ten years. A few years ago he thought it desirable that the Government should furnish the House of Commons with an account of the results of their operations; and, if he recollected aright, it took a year and a quarter to make up the account, showing the amount of capital expended in the construction of the telegraphs, the working expenses, and the annual income derived from them. The result proved the operation to have been most disastrous in a commercial and financial point of view; but it served to illustrate the way in which the Government proceeded, at variance with every principle of well-regulated industrial undertakings. When the telegraph was commenced, the question of the general course which the main lines of railways in India should take, had been much considered. It would naturally occur to the mind, that in laying down lines of telegraphic communication they should follow, as far as possible, the anticipated routes of the railways; so that when the railways were complete, the telegraphs could be brought along them; thus the railways would derive advantage from their connection with the telegraph, whilst the latter would be under the protection and supervision of the railway administration. But the Government selected a different route. The consequence was, one system of telegraphs for the railways, and another system under the charge of the Government, each going through different parts of the country to the same termini, the Government route traversing districts rather inaccessible, so that there was difficulty in watching over it and in keeping it in repair. In some instances, the Government telegraph was carried through jungle where there were no inhabitants, and where the wires had fallen down and remained neglected for a considerable period before the defect was discovered. So great was the interruption to messages, that when he was last in India, it was the custom to announce affirmatively what lines were in working order, the negative being assumed with regard to the others; the precaution being given that if a message was to be conveyed with certainty, it was desirable to forward it by two routes. Thus a message from Bombay to Calcutta, should be sent both by way of Agra, and also round by Madras to Calcutta. With the two routes employed, there was a chance of one succeeding; but, notwithstanding, sometimes a letter by post would prove the more certain and rapid means of communication. He believed these difficulties would remain, so long as the Government had possession of the telegraphs in India, and further, that a good system of communication between the chief cities and towns would not be obtained till the lines were given up by the Government, and were concentrated for all commercial and public purposes upon the main lines of railways in that country. By the connection of the telegraphs with the railways alone, would an effective staff be found for carrying on the operations: and that would also be a check to the natives going into the jungle and reading off a message. As to the further extension of the system, it was of importance that a telegraph, although submarine, should follow, as nearly as possible, the existing line of commercial communication, so as to secure not merely the through but also the intermediate traffic. If the Russian line were made, the intermediate communication along its whole course, from the north of Asia to the west of Europe, would not equal the valuable intercourse between Hong Kong, Singapore, Calcutta, and Bombay. He thought it was desirable that the lines should touch at, and connect all the great ports in the East, so as to have a complete system of intercommunication, as well as a complete through communication, from China and Australia to this country. It had been suggested that a line might be taken from the head of the Persian Gulf to Beyrout, through what had been called a desert country, but it was not so in fact, because in the central part, there was not only an established Government, but one of a very absolute and despotic character, under the Wahabee chief; and it was not possible to carry a line of communication through that region unless it were conceded by its despotic ruler. At the same time, if it could be established, it would be a better route than the one through Asia Minor, where there were unruly tribes. Beyrout might easily be connected with Europe, but that would depend entirely upon diplomatic relations. He was afraid it was with the Turkish Government, as with the Indian, difficult to induce them to conduct telegraphy in a proper manner, and equally difficult to induce them to put it into the hands of others. Attention should be directed to a new route from the Persian line, rather than to the improvement of that which was now used; as the perfecting of the Turkish line, which occupied about a fourth of the whole distance from London to Kurrachee, would, in his opinion, be a difficult, if not an impracticable, undertaking.

Major CHAMPAIN said, having been engaged in connection with the Indo-European telegraph since February, 1862, when Colonel Stewart and himself were sent by Lord Canning to Teheran, he thought it was his duty to do what he could to clear up a few misconceptions, and to remark upon some of the suggestions which had been brought forward. It was certain that the telegraph between England and India was not at present satisfactorily answering the calls made upon it, and it was equally certain, that the difficulties could be traced to mismanagement both in European and Asiatic Turkey, and in India. As to the faults of the present system, beginning with that of the Ottoman administration, it was probably known that the Turks kept the managements of the lines jealously in their own hands; and that in cases of the most obvious neglect and bad arrangement, all that could be done by the English officials, was to remonstrate, either directly with the Turkish telegraph directors, or indirectly through the British Embassy with the Porte. The occasions on which instances of carelessness, false economy, and want of system had rendered it necessary for complaints to be made, were so numerous that it would be tedious to refer to them, but he regretted to say that little, if any, improvement was hitherto perceptible. Quite lately, the line had been working rather better than previously, but in October, the Turkish portion of the route was in a worse condition than when first opened. It was scarcely necessary to dwell on the immediate causes of failure, yet while on the subject, he would give one instance to account for some of the recent and most vexatious delays. About a month ago a disturbance took place at Erzeroum, and the local wires from Constantinople being out of order, the Turkish Government seized upon the British line, exclusively, for four days, or five days. This occurred, notwithstanding the strong remonstrances of the British Commissioner, Mr. Courtenay, and of the Turkish Director-General, and in direct violation of an important article in the treaty, which provided that one wire at least should be invariably devoted to Indo-European traffic alone. In this case, Mr. Courtenay was compelled to telegraph to England to stop future messages being received for transmission, and as it was, a great number of despatches were detained for days at both ends of the lines. Major Champain believed that a line worked by Turks would never come up to the European standard of efficiency.

There were but two practicable ways of reaching the Persian Gulf cable from England—one, through Turkish territory to the head of the gulf, the other through Russian territory to Fabreez, and thence to Bushire. He thought that, in course of time, the line, which was now actually at work, through Petersburg and Tiflis to the Indo-European telegraph office in Teheran, would be regarded as the best means of communication with India; but it must be borne in mind, that it was at present wretchedly organized, and that Russia would scarcely go to the expense of putting it in order, and employing clerks acquainted with the English language, unless some portion of the Indian traffic were guaranteed in return. When it was remembered that Turkey had constructed an expensive line from Constantinople to Bagdad, solely at the request of the British Government, and on condition that a cable should be laid along the gulf, nothing need be said to show that it was a delicate question as to how far assistance could be given to a scheme, which, by transferring all the traffic from Turkey to Russia, would possibly ruin the Bagdad line. He was convinced, that if both lines were at work there would soon be developed a traffic sufficient for both, as well as for another cable, such as that which had been described in the Paper.

Bad as the Turks were, it was not fair that more blame should be imputed to them than was deserved, and it was only right that he should mention one case, where, he conceived, they had been wronged by public opinion. During the months of May and June, 1865, before many complaints of delay had been publicly made, the London offices, without due inquiries, took on themselves to divert more than four hundred messages from the regular channel, and to forward them by Petersburg to Persia. Every such message had to be translated into Russian, then into Persian, and back into English, on reaching the office at Teheran. To crown all, the wire was broken at the Russo-Persian frontier, and out of the four hundred messages alluded to, none reached Teheran except by courier: all were at least thirty days *en route*, and scarcely one was intelligible. When the first was received by Major Smith, the director at Teheran, he telegraphed to Major Champain, and the London officials, at Colonel Goldsmid's request, agreed to send no more for the present by that line. Great blame was due to the London offices for this. It was true the Turkish line was then working badly, and messages were taking eight days and nine days between England and India; but by the Russian lines, as he had stated, at that period none took less than thirty days, and nearly all the four hundred were mutilated and utterly unintelligible.

It had been suggested, in the course of this discussion, that a line should be constructed to join Bagdad with Beyrout on the Mediterranean, and it had been stated, that such a line would pass through a country, which could hardly be correctly termed a desert. Having ridden from Bagdad to Hillah, and beyond Hillah to Damascus, a distance of nearly 400 miles, he could only say that a more unmitigated desert could not possibly be conceived; there was not a single building, nor a blade of cultivation. The few Arabs who were now and then to be met with, were wandering robbers, who owned no authority but that of their own sheikh; and there were but one or two wells on the whole line. One of the officials lately employed in Mesopotamia, Mr. Percival, did endeavour to make his way from Damascus to Bagdad; but, like almost every European who had taken that route, he was stripped of all he possessed. An account of his troubles would, if narrated, convince any one of the enormous difficulty there would be in constructing and maintaining a line of telegraph in such a place. As for the Wahabee Government having anything to do with it, if Mr. Palgrave's map might be trusted, the direct line from Bagdad to Beyrout would not run near that territory, nor within 500 miles of the Wahabee capital. But supposing there were no physical difficulties to be encountered in carrying out such a scheme, who was sanguine enough to suppose that the Turks would agree to take the traffic off their long line from Belgrade to Bagdad (the greater part made expressly for this Indian communication) to send it through a short line, such as the one under consideration? As every inch of ground between Beyrout and Bagdad was claimed by the Porte, he thought such a line could not be made without their permission. Before quitting this part of the subject he would repeat his conviction, that the choice lay between a Turkish line and a Russo-Persian one, and that the present line was the only Turkish one that could be expected, or, in fact, that was needed.

With regard to mismanagement in India, the Government was fully alive to the necessity of taking active measures for putting the lines in more satisfactory order, and already, some decided steps, with this object, had been taken, both in India and in this country. The late Director-General of Indian telegraphs resigned his appointment in July, 1865, and was succeeded by Colonel Robinson, of the Engineers, whose previous services made it certain, that whatever talent and energy could effect, would be done. Great changes in the department had already taken place, and large quantities of new material, of the best description, were now being sent from this country. Some little time, however, must elapse before a marked improvement could become apparent, but there was no doubt, that a change for the better in the Indian telegraphs might shortly be looked for. It appeared to be thought that telegraphs should be erected only along the lines of railway. At the present date, there were but 4,886 miles of railway in India, including even those in course of construction, while the Government telegraph lines extended over 12,000 miles. As a general rule, the telegraph lines followed the roads, and the distressing descriptions of the posts falling down in the middle of dense jungles, and of the consequent interruption to the communication, were scarcely according to the real state of the case. It had been urged that the telegraphs could not possibly be properly worked under Government direction, although the postal arrangements, which were infinitely more extended, were carried on admirably. The statement, that Government messages when forwarded by telegraph were also sent by post, required no explanation; for he believed that, even in England, all important orders sent by telegraph, were confirmed by written copies, forwarded in the usual way. After all, the management of the companies, whether telegraph or railway, was by no means perfect, even in this country, and he had no doubt that there were many instances of delays and mistakes quite as bad, though not quite so frequently occurring, as those which had been dwelt on with such emphasis. That the Government had hitherto dealt, and was still anxious to deal, with this Indo-European scheme in the most liberal manner, could not be denied. In proof of this, it was only necessary to refer to the admirable arrangements with regard to the laying of the Persian Gulf cable, sanctioned by Sir Charles Wood, and carried out so ably by Colonel Stewart, and by Messrs. Bright and Clark, without the occurrence of one single failure. Anxious to do all in its power to encourage improvements in submarine telegraphy, it had been the first to give Mr. Hooper an opportunity of exhibiting the advantages of his new india rubber core; and the satisfactory results of the experiment, as far as it had gone, had been already alluded to by the Author.

He would conclude by expressing the earnest hope and belief, that the difficulties which were plainly enough visible, would gradually be surmounted, and that before long the extension of the system to China and Australia might be determined on, and another cable be submerged in the Persian Gulf, as successfully as the present one had been. Even after what had been so well and so feelingly said, regarding the labours of the late Colonel Stewart and their sad termination, he could not refrain from bearing heartfelt testimony to those rare personal qualities which endeared him to all who served under him, and which would render his name one never to be forgotten by any who had even the smallest share of work in connection with the Indo-European telegraph.

Mr. R. W. **Crawford, M.P.**, said this was a subject in which he took great interest, partly from the circumstance that he belonged to that class whose interests were so much affected by the wretched mal-administration of the telegraph to India; and partly because, being connected with Indian railways, and concerned in the management of the East Indian line, he was of opinion that the proper mode of carrying on telegraphic communication in India should be by the instrumentality of the railways. The statements made by the Author, relative to the present system of management of the telegraph to India, Mr. Crawford could endorse to a great extent, and he must say, that being under the necessity of sending messages to, and receiving messages from, India on nearly every day in the week, it was seldom that he got a message from India without its requiring the exercise of all his own ingenuity, and that of his partners and of the clerks in his office, to decipher what had been sent. He could mention numerous misinterpretations of messages sent to India, some of which would be amusing, but the real question was—What was the remedy for this state of things? His own opinion was, that the affair should be taken out of the hands of the Government, as he considered that, so long as the transmission of messages to and from India for mercantile purposes was a matter of profit, the Government ought not to be entrusted with the charge of carrying those messages. Some time ago, a proposal was made to establish a public company, to take up the matter of Oriental telegraphic communication, including the carrying of messages within India itself. After communicating with the different Indian Railway Companies, as to the conditions on which messages should be carried upon the wires alongside the railways, it was arranged that the posts should be made of sufficient strength to carry a certain number of wires, and that the Telegraph Company should rent from the Railway Companies the privilege of having two, or more wires appropriated to their purposes. In doing this, the Railway Companies acted on the principle, that the business of a railway was to convey passengers and goods, and that the transmission of messages, except for the purposes of the railway, was not the object for which that Company was formed. Moreover, it was considered, as far as the public was concerned, that a body of persons acting together as a Telegraph Company, could perform the service of the public better than a Railway Company, whose minds were applied to different objects. These terms having been agreed to, which, as far as the Railway Companies were concerned, afforded little emolument beyond an indemnity for the expenses to be incurred, the whole proposition was submitted to the Government, in the full anticipation that it would be immediately acceded to; but after being sent to India, the final answer was a positive refusal to entertain it. The reason appeared simply to amount to this, that the Government intended to keep this mode of communication in their own hands. He repeated his opinion, that the proper course for the telegraph wires was by the side of the railways, where they would be inspected several times in a day by every passing train, and every facility would be afforded of access for repairs; and he contended, that for the Government to retain the exclusive control over, and administration of, the telegraph in India was opposed to the spirit of the day. On the continent it was true the telegraphs were in the hands of the Government, and up to a recent period, he knew of only one little continental telegraph which was an exception to this rule, that was the line from Lucerne to the top of the Righi, which was in the hands of private individuals. The continental systems of telegraphs were certainly opposed to the views which he advocated. In England the telegraph communications were in the hands of the public, and not of the Government; on the continent on the contrary, they were in the hands of the Government, and not of the public. He maintained, that the only way in which those who were interested in commercial intercourse could hope to see communication carried out, with due justice to all the great public interests involved, was by securing the formation of a public company,'which should be entrusted with the charge of working these lines of communication. In India the thing might be easily done. A proposed company, giving, as it ought to do, a reasonable guarantee of its sufficiency in capital and intelligence to undertake the management of such a work, could better conduct communication between this country and Kurrachee, over the line made by the Government, than the Government could do it. In order to understand India, the distance from Bombay to Calcutta might be taken as being the same as that from London to Rome; and from Peshawur to Cape Comoran, as that from Lisbon to Warsaw; and those were the distances traversed by the telegraph lines in India, and all these were made to depend upon the inefficient system now in force in India.

Captain Huish said, adverting to what had been stated with respect to the relative properties of india rubber and gutta percha, that he did not think vulcanized india rubber had as yet had fair play in the test of its properties as an insulator. The difference in its cost as compared with gutta percha was only about three per cent. Electricians acknowledged that vulcanized india rubber was the better insulator of the two, and in point of durability, he believed experience would prove it to be at least equal to gutta percha. He was aware the time had not been sufficient to demonstrate accurately, which material possessed the higher enduring qualities; but he had strong faith in india rubber eventually holding its own against gutta percha, and it was undesirable to depend entirely upon the supply of one material alone for insulation. With respect to the bad administration of the telegraph between England and India, he thought he was correct in saying, that the distance through the Turkish dominions was, from Constantinople to Bagdad 1,550 miles, and thence to Fao 400 miles, making a total of 1,950 miles of the entire route through Turkish territory. Of that length 400 miles were through what was called the Arab district, and he believed he was accurate in saying, that so weak did the Turkish Government feel itself in the control of its own subjects, that it employed the British Government to superintend the construction of that part of the line which ran exclusively through the Arab portion of the route. He had been told by the superintendent of the work the singular fact, that the portion most easily maintained in Turkey, was that through the insubordinate district of the Bedouin Arabs, and this was effected by employing at every six miles along that distance, an Arab guard, who was paid 15*s.* or 16*s.* per week, but this pay was stopped if anything happened to the telegraph. Thus, in addition to the exercise of his ordinary marauding propensities, this Arab received a handsome income, and these guards took good care that their brother Arabs did the telegraph no harm. Now, this distance of 1,950 miles had only two English, and two French inspectors—the rest of the staff, including the instrument clerks, six at Constantinople, and six at Fao, was composed entirely of Greeks and Armenians, who did not understand a word of English, nor were they distinguished for habits of industry. Such being the state of matters on the Turkish portion of the line, and the messages all being repeated by Greeks and Armenians, and ninety per cent. of the messages from India being in the English language, although a larger proportion from England were in French, it was not to be wondered at that the most absurd mistakes occurred. The remedy which suggested itself to his mind for this state of things was to employ European agency, exclusively, or very largely, in the working of the Turkish telegraphs. As regarded the complaint against the Electric and International Telegraph Company, for diverting a considerable number of messages from the Turkish to the Russian route, he remarked that as ten or twelve days were occupied in getting messages through by the Turkish route, the directors resolved, as an experiment, to try the other route. He thought, under the circumstances, there were fair grounds for doing so, but he quite agreed it was not successful; and that bad as the Turkish route was, nothing was gained on that occasion, by attempting the Russian route. On the part of the Turkish officials, there was no particular anxiety or inducement to expedite the messages. Sometimes it happened that no messages were received from India for several days; but recently, on one Sunday night, no fewer than one hundred and seventy-five messages came in one after the other. It subsequently transpired that nothing had happened to the wires; but the messages had been allowed to accumulate till there was a sufficient number on hand to make it worth the while of the employés to go to the office to despatch them. So far from thinking that what was undertaken by Government must necessarily be badly done, he believed nothing could be more admirable than the postal arrangements in England; but in the management of the telegraph in India, there had been a lamentable apathy in the administration, to call it nothing worse. With regard to the establishment of a private company to relieve the Government from its present anomalous position in India, he gave his hearty concurrence to the project. He believed if the arrangements which had been described, and which had been carefully matured, had been sanctioned by the Indian Government, instead of thirty days being sometimes occupied in the transmission of a message, it would be accomplished, on an average, within as many hours. He could state that a few days ago it came to his knowledge, that at one of the four transmitting stations in Turkey, as many as three hundred messages were lying at one time, a number of them having been in the office for twelve days or more.

Mr. R. A. GLASS said, he did not propose to go into the details connected with the Persian Gulf line. He was originally consulted by Sir Charles Bright upon that specification, and the results of the working of the cable were all that could be desired. With reference to the comparative merits of india rubber and gutta percha, no doubt each material had its advantages, and he thought there was room for the use of both. He regarded the question of telegraphic communication with India as one of great importance; and being connected with the line which up to a recent period had been the connecting link with England, that from Malta to Suez, he might be allowed to offer a few observations on this subject. The Malta-Alexandria cable was never contemplated to be laid in shallow water; yet it had done good service. Upon that line being laid, there was great doubt whether the traffic at Alexandria would be remunerative for the cost of the 1,500 miles of line: the result had removed all doubt. He was present at the completion of the laying, and he took upon himself the onus of opening the line to the public. At the first starting, he found that sixteen days were occupied in getting messages from London to Alexandria, and when they arrived they were quite unintelligible. That was anything but encouraging, and the result was, he felt it necessary to obtain English control over the lines through which those messages passed. At that time the Baron Ricasoli was prime minister of Italy, and he gave permission for the Italian clerks to be superseded by Englishmen. Then, instead of fourteen days or sixteen days, the messages were transmitted in two days, and, instead of being inexplicable, they were perfectly plain; and before leaving Alexandria, he had the satisfaction of seeing messages arrive in three hours in an intelligible form, a hundred together for a mail, which were despatched without a mistake. The effect of this was, that the receipts rose from £200 to £3,000 per week. However, on Baron Ratazzi coming into power, the English clerks had to be withdrawn, when the messages again became unintelligible, and as a natural consequence, the receipts fell off considerably. A good deal had been said about the rival line to India. From the experience he gained in Egypt, he agreed with what had been said as to the indolence which prevailed amongst the Turkish staff, which prevented their executing the work properly. This was the case with all Orientals; and, although the Viceroy of Egypt possessed six or eight wires from Cairo to Alexandria, it suited him to pay £400 or £500 a year for the perfect and speedy transmission of his messages by means of the Suez and Alexandria line, which was worked by English clerks. In reference to a line to India that might be relied on, it struck him that it was a mistake to have lines through one district only. One set of wires might be swept away for a long distance by a storm, and quarrels between tribes in the East led to the stoppage of the telegraph altogether. He advocated duplicate or alternative lines. If that part of Turkey and Arabia, referred to by Major Champain, could be crossed, there would be no difficulty in getting through Egypt, as far as the lines of the Viceroy went. With reference to the Red Sea line, no one would say they could not lay a cable from Suez to Aden which should be permanent. Many cables had lasted fifteen years, and were still in working order. The cable from Aden to Kurrachee established a connection with the Indian system; and with a proper survey, without which no cable ought to be laid any more than a railway ought to be made, and with a proper cable, there was no reason why a line of cable should not be laid from India to Australia and China. Then, there was the route by way of Russia, so that telegraphic communication from this country might certainly be conveyed to the capital of India, by one route, or the other, within twenty-four hours; and if that was accomplished as an average, he believed it would be deemed satisfactory. The land line from Suez to Suakim had been arranged, and there could be no doubt as to the extension of the system to Aden, inasmuch as the route was in shallow water, and the bed of the sea was favourable to the endurance of the cable. His experience led him to the conclusion, that nothing short of European working of the line, and the perfect control over the clerks from one end to the other, would ever be satisfactory as a means of communication between England and India. If a direct line from Holland, through the Austro-Germanic territory, or through Italy direct to India, could be made, the object would be at once accomplished; and he believed the French Government would only be too ready to co-operate in such an undertaking.

Mr. FLEEMING JENKIN remarked, as to the manufacture of shallow water lines, that there was little to be added to what had been already stated in the Paper. The route to India by the Red Sea and the Arabian Sea must no longer be regarded with fear. The failure of the Red Sea cable was not, in his opinion, due to the nature of the bottom, but arose from circumstances quite unconnected with the locality. He believed that a cable could be successfully laid in the Red Sea, and along the Arabian Sea to the coast of India; and that it was necessary to adopt this route to secure an alternative line to India. As to the further extension to China and Australia, he had long, in conjunction with Mr. H. C. Forde, and latterly with Sir C. Bright, advocated those lines. He would, however, direct attention to one point, the satisfactory nature of the communication, where effected by submarine cables laid in shallow water, as compared with land lines in half civilized countries. No complaints arose from the transmission through the submarine line to Alexandria, or on the Persian Gulf line. Occasional interruptions undoubtedly occurred; but if a duplicate line existed, as was now proposed, even that objection would be obviated. There were English clerks, as a matter of course, on the submarine lines; but there was a difficulty in getting them in Italy, Turkey, and even in India. He had made a calculation, with a view to compare the stability of submarine cables with that of land lines, and especially the land lines in India. He took from a blue book of the Indian Administration, an account of the interruptions which occurred between Rangoon and Calcutta, which, though one of the least satisfactory sections of the Indian telegraph system, was one which might have to be used from India to the East. He found that, if the same average number of interruptions per hundred miles had occurred in the Malta-Alexandria cable, as occurred in the district he had named, it would have been equal to a rupture of the cable in two places, every day in the year. That fact showed how much better it was to establish cables than to create new land lines in distant parts of the world. Submarine cables were undoubtedly more expensive; but while the Persian Gulf cable was earning more than £100,000 per annum, and the Malta-Alexandria had taken £3,000 per week, there could be no fear that they would not pay well, especially when they formed parts of a complete system. Several years since, he had made experiments on, and obtained the curve, for the variation in the resistances, at different temperatures, of commercially pure gutta percha, as manufactured in 1858; but the formula given by the Author was, he believed, quite new and extremely interesting, especially as the experiments upon which it was based, extended over a greater range, and were more carefully conducted than his own. It was exceedingly satisfactory to find how well the two sets agreed, particularly as in the Persian Gulf curve certain foreign bodies entered, under the name of Chatterton's compound.

Mr. C. F. VARLEY observed, in reference to the importance of having good English clerks at the intermediate transmitting stations, that after a line of telegraph was constructed, the management of the apparatus for working it, was considered to belong to the engineering department. But the most important part of the whole telegraph machinery, the living portion—the clerks—was generally left in the hands of those who were unacquainted with the difficulties that had to be contended with, in maintaining communication through the wires. With regard to the European clerks, who had been specially trained in this country, before being sent out to work the lines in India, it was found that the salary of £130 a-year, was in reality less than the pay of telegraph clerks in England receiving £50 or £60 per annum, and was not sufficient to induce them to remain in the service. Consequently, after learning the language of the country, they entered upon some mercantile employment, in which they could obtain four or five times as much as they received from the Indian telegraph administration. He thought the education that was necessary to make a perfect army of soldiers was calculated to unfit people for the telegraphic service; as in telegraphy every man must be always prepared to act upon his own responsibility, for telegraphic circuits were constantly liable to interruption, and those interruptions required prompt individual action upon the part of all concerned. On these grounds he could not hope for any considerable improvement in the Indian telegraph, until it fell into private hands, and was exposed to competition.

He perfectly agreed in the necessity of having more than one line of telegraph between England and India. These duplicate lines should not, however, be independent throughout, but in communication at various points; so that if one section in one route were broken, and another section in the other were out of order, the two sound sections could be combined, and one circuit be kept open throughout. This was practised to a great extent in England. Take, as an example, four wires between London and Glasgow; the first defective between London and Rugby, the second between

Rugby and Manchester, the third between Manchester and Carlisle, and the fourth between Carlisle and Glasgow. If these four wires were independent throughout, all the circuits would be useless. The practice was to connect together the three good ones of each section, and thus out of the four imperfect lines to establish three good ones. Therefore, to provide a good communication between England and India, the lines over the different routes should be run into the same office at frequent intermediate stations. Another matter of the greatest moment was, that errors would arise during transmission, especially where the clerks were telegraphing a foreign language, with which they were unacquainted. When the distance between the termini was great, the number of transmissions was frequently considerable, and the liability of errors was proportionately increased. In England, the average was below one error per hundred messages.

The telegraphs in Germany were, compared with those of the rest of Europe, very well managed. If, therefore, a route were opened from England, through the Austro-Germanic territory, to Alexandria and Suakim, and thence by cable to Aden and Bombay; Italy, France, and Turkey would be excluded from the route. Mr. Glass had already obtained, from the Turkish Government, permission to erect wires through Egypt, from Alexandria to Suez; and there did not appear to be any reason why the British Government should not obtain similar powers between Constantinople and Bussora. The telegraphs in Russia were better managed even than those of Germany, and prior to the political disturbances in Poland, by which the communication between Russia and England was deranged, as many words per minute could be transmitted direct from London to St. Petersburg as to Berlin, and not unfrequently a higher speed was obtained. This reminded him of a discovery which was made during the late Schleswig-Holstein war. When that war broke out, the telegraphs were blocked with messages, and serious delay resulted. The Prussian Government had, up to that time, adopted the plan of fining the clerks heavily for all the errors traced to them, and it was therefore their interest to transmit as few messages as possible; but by giving each clerk a small sum for each message transmitted correctly, a considerable improvement was effected, and the speed of the messages from Berlin to London was increased, in the ratio of about 7 to 12. That plan should be adopted in India and in Turkey. It had been stated, that the Electric and International Telegraph Company ought to be blamed for having sent messages through the Russian route. The experience of working direct from London to St. Petersburg, compared with London and Constantinople, was so favourable to the former, that if it had not been for the abnormal state of the line between St. Petersburg and

Teheran, it would have been found superior to that *viâ* Constantinople, and he believed the Russian route would shortly be found far more expeditious and accurate than the Turkish.

Vulcanized india-rubber had not yet had a fair trial. He was happy to say, six months ago, at his suggestion, the Directors of the Electric and International Telegraph Company decided to give Hooper's wire a trial, and one of the wires in the cable to be laid between Portpatrick and Whitehead was insulated with vulcanized caoutchouc. That cable was completed within a mile and a half, and he had been puzzled to get an accurate determination of its insulating power, because the loss was so small. The insulation was in fact, so high, that it was impossible to get a reading of the true leakage through the india-rubber without a still greater leakage over the ends. He had found it necessary to have all the ends cut clean, put through corks and placed in a bottle, the sides of which were moistened with sulphuric acid, to dry the atmosphere; with these precautions the reading obtained was 373,000 millions of ohmads, or British absolute units, which he still believed to be considerably under the mark. Such enormously high insulation was of great value to the engineer; it enabled minute defects to be discovered some time before they could be detected in long cables, supposing gutta percha to be used. But when the cable was down, that amount of insulation ceased to be of any great value; for gutta percha gave, after the cable was down, many times the insulation really necessary. Mr. Hooper's material had the advantage which characterized all india-rubber compounds, that its inductive capacity was smaller than that of gutta percha. Experiments showed this to be in the ratio of 100 to 137, and it represented, to the commercial world, the important result, that a cable which cost a certain sum of money would be capable of earning £137 in the same time that one insulated with gutta percha earned £100; in other words, a cable which, insulated with gutta percha could only just pay its expenses, when in full work, would, if insulated with this material, pay a dividend equal to 37 per cent. of the working expenses. This proved that it was a material which should be carefully looked after, by those who were interested in deep-sea cables. The fact, that the material might be heated to the boiling point of concentrated salt water, was one of great importance in a line like that of the Red Sea, or where there was reason to fear hot springs. It was desirable, that cables insulated with this material should be submerged in different parts of the world, so that information might be obtained, as to its durability. At present it had not been sufficiently tried to warrant its adoption for long and expensive lines. It was now receiving its first trial, in the Portpatrick and Whitehead cable, which was composed of seven single cables twisted together, each cable being covered with ten No. 8 galvanized charcoal iron wires of excellent quality. This cable was made in 1853, by the manufacturers of the Red Sea cable, and was tested under water throughout its manufacture,—a most necessary precaution, but wholly neglected when the Red Sea cable was manufactured. These cables were laid down in 1853, between Orfordness and the Hague, and were picked up in 1863 and 1864. They were now being spun together, previously to being laid from Portpatrick to Whitehead; and the greater part of the iron covering had not entirely lost its galvanizing. He had noticed that in submarine cables, the iron, which was of good quality, did not deteriorate in sea water to anything like the extent which common qualities of iron did; and he was confident, that a less weight of the best wire was a better protection than a much heavier weight of inferior metal. He recommended the use of galvanized wire in all cases. In the case of the Atlantic cable, in several instances the wire was rusted in small patches; but if it had been galvanized that would have been avoided. To the extent of 99·9 per cent. the wire was quite bright, but in certain patches it was thin and wearing through by oxidation.

In connection with overland telegraphs, he had made experiments with different qualities of annealed wires. The general idea that the galvanizing reduced the strength of the metal was fallacious. In most cases where the galvanizing was properly performed, the strength of the wire was a little increased; without its power of elongation being reduced. Submarine telegraphs in shallow waters were exposed to different kinds of serious injury. A cable laid on a sandy bottom, if covered, would remain uninjured for years. Experience, however, showed that here and there the cable was laid over a stone, a piece of projecting rock or hard ground, and at these places the iron would rapidly perish. Such exposed patches generally extended only a few feet, often only a few inches. After ten years' experience, in laying down and in picking up cables in the North Sea and elsewhere, he felt convinced that the wisest policy, with regard to submarine cables in shallow waters was, after they had been laid a certain number of years, to pick up the entire cable, bring it into store, examine it, mend the weak places, and re-lay it, when the cable would be nearly as good as it was at first. By this plan the life of a shallow-water submarine cable would be prolonged three or four times, with only a trifling outlay. If a cable in shallow water were left too long, its recovery became difficult and expensive, from breaking at those places where it was weakened by exposure on a rock; if not left too long, a hundred miles of cable could be picked up in from two to four days.

He recommended engineers to specify the best quality of annealed iron for cables, to limit the quantity of iron by the money to be expended upon the cable, and never to use inferior material, as the latter became honeycombed in three or four years, and frequently, in that time, lost nearly, if not quite half its strength; while good galvanized iron wasted away uniformly, and lost but little of its strength in the same time.

It had been stated, that there was a great improvement in the communication between Alexandria and England by placing English clerks at the chief transmitting stations in Italy; but it had not been mentioned, that great care was taken in selecting from the different telegraph companies the best telegraphists that could be found to work the Malta-Alexandria line; and the success of that line (for in a commercial sense it certainly was a success) was in a great measure due to that fact: for with the ordinary instruments, almost more depended upon the efficiency of those who manipulated the line than on the line itself. It was a significant fact, that Mr. Glass had obtained, and his company now possessed, a line of telegraph across the Turkish territory, from Alexandria to Suez, when the English Government had failed; and it was now proposed to carry a cable from Suakim to Aden, thence to Kourrià Mourià, and from Kourrià Mourià to Kurrachee. Mr. Varley would recommend, as the distance was about the same, that it should be laid from Aden to Bombay direct. In that way, one important commercial centre of India would be rendered independent of the telegraph lines of the Indian Government in its connection with Europe.

It was worthy of note, that the action of the British Government, in granting permission to carry telegraphs across its territory, varied in different countries. For instance, in Great Britain the lines were invariably erected and maintained by independent English companies. In India the commercial telegraph belonged entirely to the Government: but in the British North American provinces, in Newfoundland, Nova Scotia, and Canada, the telegraphs did not belong to the English Government, and were erected, not by British, but by American companies, the stock of which was chiefly held in New York. He therefore could not see on what plea, if private companies were allowed to manage the telegraphs in Great Britain and some of her possessions, the same liberty should not be allowed in India. It was about eight years ago that the telegraphic communication between Constantinople and England was opened; shortly after the opening of that communication, it was not unfrequent to telegraph direct to Constantinople from the Electric Telegraph Company's central station in London, through Berlin and Vienna. About the same time direct communication with St. Petersburg was obtained, and had improved, until the Polish rebellion broke out and deranged the telegraphic system. In fact, it had become so efficient, accurate, and rapid, that there was no transmission whatever by hand between St. Petersburg and London. But between Constantinople and London, the telegraphic system had retrogressed, and he did not think there had been direct communication for the last four or five years. The errors which arose between India and London had been already described; and it really was a matter of the greatest importance, in providing a communication, which was not merely to terminate at India, but to be extended to Australia and China, that the sources of error should be reduced as much as possible. He did not know the exact number of manual transmissions between London and Bombay, but he understood that it was not less than ten, and more probably sixteen. Now he had frequently spoken direct through Berlin and St. Petersburg with Odessa and Taganrog, in the Black Sea, a distance of more than 4,000 miles, at good speed. If such a distance could be worked through, there was no reason why communication should not be made direct from London to Constantinople in the first place: from Constantinople to the cable at Fao in the second: from Fao to Kurrachee in the third: and finally from Kurrachee to Bombay. If that were done, the number of errors would probably be reduced to one-third what they were at present; and if, in addition, in Constantinople, and at the Indian stations, good European telegraph clerks were placed, he saw no reason why the communication should not be as correct as the messages now received from Berlin.

This was a matter of great importance in connection with the extension to Australia, about which little had yet been said. Upon that subject, it occurred to him that at present there was not the necessary information to warrant the risking of an expensive cable in those seas. From Singapore to Java, on the eastern side of Sumatra, there was a perfect forest of rocky islands, but the chart exhibited, showed none, or only very few, of those islands. A gentleman who had sailed for many years in those seas, a Dutchman, had sent him a letter on the subject, which was so much to the point that, with the permission of the Meeting, he would read it:—

"9, *Friday Street, Cheapside, London.*
25 *Nov.*, 1865.

"MY DEAR SIR,

"At the discussion next Tuesday, it is likely that at last something will be said, about the continuation of the telegraph from India to Australia.

"Assuming the line to be completed as far as Singapore, the favourite notion appears, somehow or other, to be to get to Timor, and from thence to the continent of New Holland, either direct or *viâ* Papoo-land. This will involve a series of cables across a number of small straits, where violent currents run from all points of the compass, and change their direction very frequently. The different cables required on this plan are:—Malacca Straits; Sunda Straits; Balee Straits; Lombok Straits; Allan Straits Sassee Straits; Mangeney Straits; Flores Sea to Timor.

"Now, as the islands of Balee, Lombok, Sumbawa, Flores, &c., are inhabited by Bouginese pirates, and European authority, nominally exercised, affords no security to life or property, a land line through these different islands is simply impossible.

"The sea between Singapore and North Java has, in all cases, a coral bottom, here and there covered with clay, which, however, shifts with the periodical currents; and whatever route be selected, a cable will be required which can resist the rasping action of the coral, for it will never lie still.

"I would advocate a sea-line direct from Singapore to Java, keeping at least 100 miles east of Sumatra; a land line through Java, and a cable from Fjilatgap, on the S.E. coast of Java, to the coast of New Holland. Without looking at the chart, I believe the distance does not exceed 750 miles.

"These are simply sailors' notions.

"Faithfully yours,
"T. A. Rochussen."

On looking at the chart, it would be seen that, between Java and Timor, there were several islands, including Balee, Lombok, Sumbawa, and Flores, on four of which there were no less than six active volcanoes; not an inviting circumstance in connection with telegraphy. It appeared to him that, until extensive soundings had demonstrated that a cable laid in their vicinity would be free from earthquakes and hard bottoms, the only safe route for a telegraph cable between India and Australia, would be the deep-sea line from Ceylon to the little island of Keeling—a sandy island which seemed well fitted for laying a cable—a length of about 1,450 knots, and thence to Australia 1,200 knots. He would recommend, before any money was spent in those seas, that an accurate survey of that part of the world should be made, as the existing charts were lamentably deficient in information. There was no series of soundings yet published of sufficient correctness, to lead to a knowledge of the nature of the bottom, or to enable a judgment to be formed of the desirability of submerging a cable there. There were, it was understood, many unpublished soundings in the archives of the Admiralty, and he could not comprehend why this should be so, as the wreck of a single vessel upon any of these rocks known at the Admiralty, though not recorded in the official charts, would involve a greater loss than the outlay necessary to print them all.

This brought him to another question of importance, and he wished, first of all, before going into details, to draw attention to the cable laid across the Black Sea, during the Crimean war. The portion laid in a depth of 100 fathoms had no outer protection, but was simply a plain gutta percha covered wire. This was an experiment which answered its purpose, for it worked many months; and when picked up, the gutta percha covered wire was perfectly sound. In a commercial point of view the saving of such a cable was enormous; and it was his own opinion, that a cable would be safer at the bottom of such an ocean as the Atlantic, if it had no iron covering whatever. There was another reason, why the iron covering should be got rid of in long lines, besides that of its costliness. The exterior iron covering was magnetized, every time a current went through it, and the operation of magnetizing and de-magnetizing had the effect of retarding the transmission of signals through the cable: therefore there would not only be a saving of the expense of the covering, but, when the core was submerged, a greater rapidity of transmission would be effected. A specimen cable covered with strips of cane plaited, forming a complete tube, seemed well adapted for deep seas, and was worthy of a trial.

In India, the land telegraph lines were chiefly composed of thick iron wire. The thicker the iron wire, the greater the conducting power, and the ease with which the line could be worked; and the greater the length that could be worked through, without a break. In a letter from Colonel Douglas, one of the chiefs of the telegraph in India, two or three years ago, he was informed that the rate of working, from Bombay to Calcutta, was only from three words to four words per minute, and frequently signals could not be sent through at all. Those lines ought to work from sixteen words to twenty words per minute easily. The thick iron wires were supported, he believed, for the most part, on iron telegraph-poles. He had tested iron poles of many descriptions, in the hope of finding some of sufficient cheapness and strength to be used on the main lines in England, so as to save the interruptions consequent upon the almost constant repairs of the wooden poles; but they were so weak, that they could not resist even the hurricanes experienced in England. He had not seen an iron post which had more than half the strength of the ordinary wooden poles. If, therefore, the posts which were stronger and carried lighter wires were blown down sometimes by an English hurricane, one of two inferences must be the result with regard to the Indian lines—either that the hurricanes in that country were mere gales of wind, or else that the lines must be blown down with every stiff breeze. Creosoted timber was largely used for sleepers on the Indian railways, and if it answered for that purpose, he did not see why it should not equally answer for telegraph-poles, being much cheaper and lighter than iron. There was also another peculiarity about the stores sent out to India, which he could not understand. Instead of placing the wire on the side of the insulator, to bring the strain on the bolt, instead of on the earthenware of the insulator, the wire was placed on the top, so that on curves, the earthenware had to bear the whole of the strain, and when cracked, or broken, there was immediate ingress of moisture to the iron cap, and loss of insulation. In England, that plan of placing the wires had been tried, and it was found, that in sandy localities, the continual hammering on the insulator, caused by the vibration of the wires, led to their being gradually cut through by the sand, so that nearly the whole had to be replaced within two years. But when they were placed on the side of the insulators, that effect was not experienced, as the sand could not rest there; and wires which had been erected ten years did not show any material indication of wear.

One of the chief sources of interruption, in long land telegraph lines, was caused by the breaking of wires. A telegraph might be compared to a chain—one defective link threw the whole out of use. It was difficult to get iron free from all impurities; but now wire which did not break, was obtained, by having the billets rolled in pieces of from 90 lbs. to 100 lbs. each. These were then rolled into rods, and the rods were drawn into wire. The manufacturer was not allowed, if the rod or wire broke in the operation of rolling, or drawing, to join it again, and thus wire was procured without any weld, join, or splice whatever. The imperfections, in ordinary wire, were nearly all at the welds. But there were nevertheless flaws and sand splits, and these occurred sometimes to the length of twelve or fifteen yards, and when that happened the wire invariably gave way. In order to find out those imperfections, the wire was in the first instance passed under a roller, about 1 inch in diameter, then passed rather sharply up, over a second roller, and down again under a third, and this test was nearly certain to detect any fault in the wire; and if there was any brittle place, it cracked or split open in passing over these rollers. After having been subjected to this test, it was passed over a drum, 30 inches in diameter, and from that to another, 30½ inches in diameter, each drum rotating at the same velocity, consequently every part of the wire was elongated about 1½ per cent. The wires so prepared seldom broke in course of erection, and the interruptions from breakages were 95 per cent. He therefore strongly recommended, that welds and joints should be strictly excluded from telegraph wires. With respect to the joints made by twisting two wires together, when such joints were immersed in the acid pickle before galvanizing, they held a large quantity of acid by capillary attraction, and when galvanized they retained a great amount of heat. The consequence was, that however good the wire might be away from the junction, at each point of junction it was almost invariably as brittle as glass; therefore he recommended that manufacturers' joints, of every description, should be excluded from the wire altogether, the only joints allowed being those made upon the line, by bringing the wires side by side, binding them together with No. 16 galvanized wire, and soldering with soft solder; those joints, called the 'Britannia' joint, never gave way, and they should be the only ones allowed.

The Author, in Plate 1, Fig. 1, showed the method adopted for testing the small amount of leakage through the joints of the Persian Gulf cable. The joint itself was placed in a trough of water connected by a wire—in the diagram very short, but, in fact, of considerable and variable length—and that wire was connected with the condenser during the operation of discharging; the condenser only being discharged, and not the wire itself. The plan Mr. Varley adopted in testing the joints of the Atlantic cable was to connect the condenser continually on to the key, so that this wire was included. It should be borne in mind, with regard to this testing, that the amount of electricity was exceedingly small. The joints of the Atlantic cable showed a leakage in one minute of time equal only to the charge of 1 foot, and in many instances only 7 inches of the core of the cable (charged with the same power as that used in the test); an amount, which every electrician knew, was very small, and when this exceedingly small quantity of electricity had to be stored up, for the long electrical period of one minute, it was difficult to find sufficient insulation for the purpose. When the joint was tested in that form, it would be seen, on applying the battery to the wire inside the core, that the whole exterior of the cable would, if under water, be charged as a Leyden jar. The exterior surface of all cables was a semi-conductor; consequently, after applying the battery, the surface current caused by charging the exterior, would discharge itself slowly on either side, part running into the trough, and increasing its charge, and part escaping to earth along the extension of the core. Thus then, when the condenser was discharged, it gave up, not only the leakage through the joint, but the charges just explained; therefore it was necessary to put a wire on each side of the trough, to cut off this extraneous electricity. But the surface of the core being a conductor, these wires conducted away part of the electricity which was accumulating. It therefore became necessary, as this could not be stopped, to find out how much electricity had leaked out during the time the reading was taken. He would not now give the details of the process, but he proposed to furnish them subsequently, and to show how, first of all by charging the condenser with another battery, and discharging it immediately, then charging again and discharging after a minute of time, the amount of decrease in the charge, by leakage during that interval, might be ascertained, and thence how much the gradually augmenting charge from the joint had lost, during the time of the observation. It was usual to take readings after five minutes of time, but the shorter the period of time was, provided sufficient charge for a reading were accumulated, the more accurate the result was. Without such a precaution this valuable test was an imperfect one, and always indefinite; but when worked out in the manner described, the actual leakage through the joints was expressed in definite measure, and the amount of leakage through the joints could then be compared with the leakage through the rest of the core.

Mr. H. J. ROUSE remarked, that telegraphic communication between India and England was, it might be said, one of the largest and most important themes which could be submitted to the consideration of the members of this Institution, or indeed, of any other body of the community. It meant no less than the intelligence, the wealth, and the resources of thirty millions of British subjects at one end of the wire, and the wants, the interests, and the industries of upwards of one hundred millions of the Queen's subjects at the other end of the wire. In considering the several routes available as lines of communication as well for telegraphic as for other purposes, between England and India, it would be seen, by reference to the large map, firstly, that the national high-road to India was round the Cape of Good Hope; that line, which might be distinguished as the "Long Sea Route," being not only the cheapest mode of communication between this country and India; but also the only route which, as a nation, could be taken, as well during war as during peace, without favour or permission from any foreign potentate. Then, secondly, there was the "Short Sea Route"—by the Straits of Gibraltar and the Mediterranean to the narrow slip of land which separated that sea from the Red Sea, and which he would not identify under the usual geographical description as the Isthmus of Suez, but he would call it by the short title of "Egypt." And, thirdly, there was the line followed by the existing telegraphic communication, viz., from the head of the Persian Gulf, through Persia, thence closely bordering on Russian territory through Turkey, to Constantinople, and across the continent of Europe; and this he would distinguish as the "Overland Route" to India. Having drawn attention to these three routes to India, for all purposes, Mr. Rouse submitted that, in his opinion, the real highway to India was through Egypt. At the present time about ten thousand passengers, chiefly British subjects, passed through Egypt to and from India every year. The important mails, and, too, millions of specie were also sent that way, and now troops were about to be forwarded by that route. And it could not fail to be remarked, that the passage of about six thousand relief and relieved troops on the road annually, between England and India, could not be without influence in the country, forming the only landward portion of their journey. Hence, he submitted, that the telegraph to India should now be made to follow the same Egyptian route, as these several British interests would thus mutually aid and support each other in their transit. He submitted, that the telegraph should follow the same course, as they would mutually support each other. Through Egypt, there could be no doubt, the Valley of the Nile was the right line to follow. All persons who had been in Egypt had experienced painfully, that wherever travellers separated themselves from the Valley of the Nile, there was no fresh water, and hence no cultivation, and no population, and that communication therefore became very difficult. Having entered Egypt, the right line was, he thought, to follow the Valley of the Nile, as far south as Khartoum, an important commercial centre, situate at the confluence of the Blue and the White Niles, in 15° 30′ north latitude. From Khartoum the distance to the Red Sea was about 400 miles, through a well-watered, fertile and populated country to Massowah, a port of considerable influence on the Red Sea, situate in 15° 40′ north latitude, and now belonging to his Highness the Viceroy of Egypt, a potentate who himself largely made use of telegraphic communication for the development of his country, and the advantages of which rapid form of communication for commercial purposes were largely appreciated by the people of the country—circumstances which could not fail to tend much to the security of any telegraphic line between England and India, following the Egyptian route. From the port of Massowah, it would be necessary to submerge the line between that place and Aden, the latter being one of the stations on the "Short Sea Route" to India, which should not, under any circumstances, be neglected. There was, too, in his judgment, one other important point, viz., that the Island of Perim, situate at the entrance, at the narrowest part, indeed, of the Red Sea, should be made a station for telegraphic communication on the submerged line between Massowah and Aden, as no vessel could enter or leave the Red Sea without passing in sight of the lighthouse on the small and barren British Island of Perim—a fact significative of the great importance of this natural telegraphic station. In conclusion, by means of submerged cables in sections between Aden and Kurrachee, Mr. Rouse submitted that this was the true telegraphic line to India; and in his opinion, no other route could be compared with it, having regard both to security and to facility, as well of working as of maintenance.

Mr. Francis Gisborne remarked upon the absence, in this discussion, of any sufficient distinction between shallow water and deep sea lines, which he attributed in a great measure to the fact, that Engineers and scientific men were equally interested in both, and therefore did not care to point out the distinctive features which existed in the nature of things between the two classes. There could be no doubt, that at the present time, submarine telegraphy was in the worst possible odour both with the Government and the public; and it would be agreed, by those who looked into the history of the thing, that this bad repute was due, not to the failure of shallow water lines, which rarely occurred, but in a great degree, to the failure of deep sea lines, both in the laying, and in the want of permanence. In fact, so marked was this distinction, that he might say shallow water lines had scarcely ever failed. The Channel Islands cable had failed, but it was placed in an exposed situation; and the cable was only 2 tons to the mile, which was obviously insufficient in that situation; while the Singapore and Java, which also failed, was only 1 ton to the mile, being also laid in an exposed position, and in a general depth of only 11 fathoms. With regard to deep sea lines, many had failed in the laying, and none had lasted longer than two years; and therefore he had been astonished to hear it asserted, that if the Atlantic cable lasted for one year it would last for a number of years. The Mediterranean deep sea lines were laid in similar depths to the Atlantic, namely, from 1,000 fathoms to 1,900 fathoms, and the longest of those lines was only one-fifth of the length of the Atlantic cable, and had not lasted two years. The Malta and Alexandria was a shallow water line. The sections of the Red Sea and India line were intermixed, being laid partly in deep, and partly in shallow water; so that one-half the line was laid in less than 100 fathoms, and the other half in deeper water. The cables laid respectively from France to Algiers, and from Toulon to Corsica, had the same outer covering as the Atlantic, namely, iron or steel covered with hemp, and neither had lasted beyond two years. It was therefore quite evident, that Engineers, and those interested in the science of telegraphy, must have the boldness to state that one class of lines had failed, though another class had succeeded. He was far from discouraging deep sea telegraphs; but experiments ought first to be made on a small scale, till some reliable evidence was afforded, that such lines could be made permanent.

As to lines passing through foreign countries, it was clear, that so long as dependence was placed upon such lines, political difficulties would occasionally arise; and in disorganized countries, like Turkey and Persia, those difficulties might be expected to be considerable; and he thought it was hopeless to expect that any communication worth having, could, speaking of a cycle of years, be permanently established through countries like Asia Minor and Persia. In condemning deep sea lines, and land lines through foreign countries, he was prepared with an efficient substitute. The configuration of the globe was such, that by making deviations, almost every considerable country could be reached by a system of submarine coast lines, laid in shallow water, and divided into short sections. America seemed to be the only exception, though even in that case, a cable could be laid along the coasts of China and Kamschatka to Behring's Straits, and thence along the coast of America to California; though he admitted that the icebergs would rake up any cable laid in shallow water in Northern regions. His long connection with the lines projected from Singapore to China and Australia led him to say a word on that subject. Those lines would, for the most part, be laid in shallow waters, in depths not exceeding 40 to 80 fathoms. Between Penang and Singapore, there was an available general depth of only about 27 fathoms, and there was danger from anchors in the Malacca Strait. Then, from Singapore to Hong Kong and Shanghai there was a depth of 50 fathoms, without danger from coral reefs or rocks, for those could be avoided. Between Singapore and Batavia, the depth did not exceed 23 fathoms. Between the east end of Java and the head of Gulf Carpentaria, the soundings were between 40 fathoms and 80 fathoms. There was a space, however, of 450 miles between Celebes and Timor, where there was a total absence of soundings. On behalf of an embryo company, he had had considerable correspondence with the Admiralty, endeavouring to induce them to have detailed soundings taken, from Java Celebes and Timor, and thence to the northern coast of Australia; but they refused to do so, probably thinking the company was not in a position to carry out the works that had been projected, owing to the continued failure of deep sea lines. Between Timor and the opposite Northern coast of Australia, the soundings ranged from 40 fathoms to 80 fathoms. A line from Galle to Keeling Island and the western coast of Australia, which would be a deep sea line, had been mentioned as preferable to that which Mr. Gisborne had sketched out from the east of Java by Celebes and Timor to Gulf Carpentaria, and an opinion had been expressed in favour of a rattan cane outer covering for the cable, but in this he had little faith. He read the past history of submarine telegraphs as condemning deep sea lines; and in these remarks he wished to raise a point, to which due importance had, unfortunately, not been given.

Mr. LATIMER CLARK said, a broad distinction had been made between deep sea cables and shallow water cables, which he could not admit. There had been failures in both; but instances of the successful repairing of deep sea cables were not wanting. He could not agree with the statement, that all deep sea lines had been failures, and all shallow water ones successes. He could mention many shallow water cables which had failed, and he believed that they exceeded in length, those which had been laid in deep water. He regarded the greater portion of the Red Sea line as a shallow water line; and the failure of that cable was not attributable to its depth, but because the cable itself was not of suitable character. The great want of confidence in submarine telegraphy, on the part of Government and the public, owing to the frequent failures of telegraphs, was much to be deplored. He did not think, however, that the members of the profession, or the public, were sufficiently aware of the improvements which had been made in telegraphy since the occurrence of those failures; and a brief reference to some of those improvements might, he hoped, in some measure tend to restore confidence, in what was one of the most profitable means of investing money which offered itself at the present day. He might say generally, that there was no branch of telegraphy which had not undergone improvement. In regard to the quality of the copper of the conductor, that employed a few years ago would carry only about 50 per cent. of the amount of electricity as compared with that now employed. It had been remarked, in reference to the segmental conductor of the Persian Gulf cable, that that form would not be used again. His object in designing the segmental wire had been to obtain the advantages of a solid conductor, while retaining the security of a stranded one, and in this he had not succeeded; but though for a deep sea cable he should certainly use a stranded wire, still for a shallow water cable he should continue to prefer a solid wire, which greatly accelerated the speed of transmission. In deep water a breakage was a serious thing; but in long lines laid in shallow water, or along a coast, a break was of no great consequence, and it was well worth while to incur the risk of fracture, in order to obtain the additional speed through the cable. In the Persian Gulf line a break occurred, owing to the wire being brittle, but it only took twenty-four hours to repair it; and now it was once down, there was not the slightest chance of its breaking again.

In gutta percha great improvement had been made, and this was entirely due to the care bestowed upon its manufacture. In the specification for the Persian Gulf cable, the Gutta Percha Company would only agree to supply wire having 125 millions of units resistance. Lately, it was specified as high as 150 millions, and in practice, 200 millions would be reached. One of the chief points of improvement in the gutta percha was, however, in its perfect uniformity. About five years ago, one of the dangers attendant upon deep sea telegraphy arose from the presence of small incipient faults in the cable, which only developed themselves after it was laid, and soon became of such magnitude as to interrupt the working. But by the care now exercised in manufacturing and testing the cables, and the accurate system of measurement which had been brought to bear in every stage of the manufacture, this serious evil had been entirely obviated, and now cables rarely went wrong if, when first laid down, they were what electricians called 'perfect.' The system of joint testing by accumulation, which had been alluded to both in the Paper and in the course of the discussion, was highly satisfactory.

Another improvement, consisted in the use of hemp saturated with water, or tan-liquor instead of tar. When Stockholm tar was used, it had frequently been the case, that some injury or imperfections in the cable, from the presence of foreign substances, had been temporarily insulated by the tar; but after a time, the tar disappeared, and the fault showed itself.

Then there was a new material in Mr. Hooper's core, which the Government had been amongst the first to encourage, and they had had some twenty-five miles manufactured, which Mr. Latimer Clark was now testing, with results far beyond those of gutta percha. The Author had stated, that the ordinary testing for resistance was about 8,000 millions of ohmads per knot, whereas gutta percha gave only about 180 millions. Mr. Varley had stated that in testing this cable he had obtained a much higher resistance, namely, 353,000 millions of units, instead of 8,000 millions. He would observe, that electricians were endeavouring to dispense with those enormous numbers. These discrepancies might create some doubt, as to the accuracy of electrical measurement in general, or perhaps give the impression that the measurements were only imaginary. He would explain how this apparent discrepancy occurred. When a galvanometer was applied to a submarine cable, to measure the amount of electricity which entered into it, the first effect seen was the well-known momentary rush of electricity, called the charge by induction, which was the principal cause of slowness in the transmission of messages through long cables. The next effect visible on the galvanometer, was the passage of the current entering the cable, and leaking through its substance. At first this leakage was comparatively large, but it rapidly became much less: for hours it would go on diminishing, and the insulation getting more perfect. On investigating the cause of this, it was found, that there were two distinct currents entering the cable; one caused by the leakage through the body of the cable, and the other due to the phenomenon called absorption, or electrification. This phenomenon was analogous to the absorption of water by wood, or paper. The electricity appeared to enter into the interior of the gutta percha, and to be there stored up inductively, entering in large quantity at first, but rapidly getting smaller in quantity, and ceasing altogether after an interval of some hours, the gutta percha having by that time absorbed all it could; and if the cable was now removed and connected with the earth, this electricity would continue to come out of the cable for hours, at first rapidly, and afterwards more slowly. In some cables, the quantity of electricity so entering

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was at first twenty or thirty times greater than the true leakage itself. In measuring a cable, therefore, in order to specify its resistance, it became necessary to define the period of time during which the cable had been previously electrified. This was generally taken, by common consent, at one minute after the application of the battery. Mr. Varley had, he believed, taken thirty minutes, and this alone would nearly account for the difference. The second cause would be the temperature of the material itself. It had been the usual practice, to give the measurement of all cables at 75° Fahr.; but he had been informed, by Mr. Varley, that his measurements were made at 53°, which made an enormous difference in the insulation. The diagram and formula given in the Paper, afforded the means of calculating the resistance of gutta percha, at all temperatures between 32° and 90° Fahr.

For the outer covering of the cable, two new materials were introduced—steel and homogeneous iron—and a third had been mentioned, and had recently begun to attract notice, viz., rattan cane, which was said to resist the teredo, and to form an effective covering. With respect to iron, all the great failures had resulted, more or less directly, from the corrosion of that metal. Cables which he had laid, for the Electric and International Telegraph Company, from England to Holland, had perished entirely where fully exposed to the flow of the tide; but wherever the cable was buried in sand or mud, it was, even after three years' submergence, so little injured that it was difficult to tell it from a new cable; and he had recently seen other portions of the same cables, which still presented so little appearance of change, that he saw no reason why they should not be good a century or two hence. But, on the other hand, where they laid out of the mud, and were subjected to a heavy tide-way, they were rapidly corroded, the deterioration having been apparently dependent on the amount of wash of the tides; and just in proportion as the cables were protected from the action of the sea water, so long they lasted. He had endeavoured to imitate this condition of things, and in 1859 a cable laid to the Isle of Man was covered with a coating of asphalte and silica. That cable was now working, and, judging from specimens which had been lifted, it was still in the same state as when first laid. The method of applying the asphalte had, since then, been much improved, and it had been used to protect the Persian Gulf cable and many other cables, and he believed, that that compound would be as durable in sea water, as coal, or amber itself.

He thought the result of the several improvements referred to, would be to render submarine cables profitable investments. Some years ago the late Mr. Robert Stephenson stated, at a meeting of the Electric and International Telegraph Company, that from an examination into the subject he had formed the opinion, that no submarine cable could possibly pay, inasmuch as it was so subject to oxidation and other injuries. That opinion had, he believed, been mainly caused by communications he had himself made, when anxious to impress upon the Electric Telegraph Company the evils arising from the oxidation of the iron covering of the cable, and the merits of the asphalte compound he had invented. The profitable nature of submarine cables had, however, been exemplified in the case of the Malta-Alexandria line, on which £3,000 per week had been taken, or equal to £150,000 a year, on a capital of £400,000. The Persian Gulf cable had been working only a few months, and had been injuriously affected, by the irregularity in the delivery of the messages sent through Russia. Yet even under these adverse circumstances, that cable was paying at the rate of £100,000 a year upon a cost of £400,000. He believed, therefore, there would soon be a similar revulsion of feeling in favour of submarine cables to that which occurred in favour of railways throughout the country some few years ago.

With respect to further improvements, to be hereafter introduced into the system, he would mention, first the codification of words of frequent ordinary use in the transmission of messages, by a careful and judicious system of abbreviation, which would leave the word still perfectly intelligible, such as *tgph* for telegraph, *cmon* for communication, &c.; if this were adopted, a much larger amount of work could be done than at present. Again, at least forty per cent. of a message was taken up by the necessity for giving long addresses. He proposed a codification also of the addresses of those persons who used the telegraph extensively; and that by the payment of a small annual fee, they might register and use abbreviated addresses, which might be printed, and be distributed to all stations, in England and America, and thus the whole of the message might be occupied with useful matter.

In 1861-62 he was sent out to examine into the condition of the Red Sea cable, and to report upon the cause of its failure. He had the cable lifted in many places, along its whole length from Suez to the entrance of the Persian Gulf and Kurrachee, and he could say positively, that there was no difficulty in laying a cable in shallow water along the whole route. The supposed difficulty in the Red Sea with regard to coral, was not a serious one. Coral never rose from a great depth of water, and it was easy to survey and select among the coral reefs a line on which to lay the cable; or, what was much safer, it might be taken in deeper water outside the coral rocks, where a soft mud was found to prevail, generally arising probably from the débris of the coral itself. All along the coast of Arabia there was a favourable bottom, and there were places for stations where the natives were friendly, and, in fact, he had no hesitation in saying, that no difficulties of a serious character presented themselves. He would advise going some distance up the Nile, crossing the desert to the Red Sea, thence to Aden and Muscat, and so on to Bombay. It had been shown, that the Turks would not take the trouble to work their telegraph lines themselves, although they were so profitable to them, and from feelings of jealousy they would not allow Europeans to do it; and therefore, he thought the time was come to carry out an alternative route by the Red Sea.

Mr. C. F. VARLEY said, in reference to the remarks as to the insulation of wire covered with india rubber by Hooper's process, and which remarks might cause some doubt as to the very high insulation he had found with this wire, that he had tried a fresh series of experiments upon a wire of much smaller dimensions, covered to merely $\frac{1}{6}$-inch diameter with Hooper's material, and 6 yards in length, being a piece from a length of 200 yards recently made. The ends of the wire were cut clean, heated to about 300° Fahr., and coated with hard paraffin to reduce the surface leakage. The wire was then charged with a battery of 500 cells, and discharged through Thomson's galvanometer, giving a swing of the image over 230 divisions of the scale. It was then charged for an hour, then removed from the battery, left for an hour, and discharged. The leakage was found to have been very small. The wire was again charged by one hour's contact with the battery, from 10 o'clock to 11 o'clock on Friday night. It was then left till 8 o'clock on Saturday evening, care being taken that no fire, or flame was allowed in the room. At 8 o'clock on Saturday evening, 21 hours after being charged, the discharge gave 117 divisions, rather more than one-half of the original charge remaining. The wire was then again charged and discharged through the galvanometer, to see that the sensibility of the instrument had not varied. The swing was 235. The wire was again charged by contact with the battery from 10 to 11 p.m., and left till the next evening at 6, when it was discharged through the galvanometer, producing a deflection of 133. His previous statement was based upon experiments made with a length of 25 miles of Hooper's wire, of large size, and the test was made with an electrometer. The present test was made on small wire of short length, and with a galvanometer; consequently, the conditions were all reversed. The long wire with the electrometer, at a temperature of 54° Fahr., required 15½ hours to go from charge to half charge. The short wire with the galvanometer, probably under more careful circumstances for insulation of the ends, required more than 21 hours to go from charge to half charge. As the ratio of the diameter of the copper of the small wire to the insulating material, was greater than that of the cable tested, the insulation, measured in units, would be higher, and if worked out, would be something like a billion, *i. e.*, a million of millions, of ohmads, per nautical mile. The temperature of the wire last tested, varied from 50° to 60°. It was left in a room without any fire, for in testing short lengths, such as 6 yards or 7 yards of wire, care must be taken to have no flame in the room, as flame, though at a distance of 10 feet or 12 feet, had the power of running off with the charge, and so reducing the apparent insulation.

Mr. JOHN MACINTOSH said it appeared to him, that the true cause of failure of deep sea lines was attributable to the mode of construction adopted, more particularly as regarded the iron wire and hemp spiral coverings, which he considered quite unnecessary. In the india rubber insulation around the wire he exhibited, there was a tape spirally wound round, which evidently gave no longitudinal strength to the cable. But when the india rubber was applied in numerous thin coatings, it acquired great longitudinal strength. It was almost impossible to tear it asunder; and this great longitudinal strength was obtained without the aid of foreign materials. The vital parts of the electrical cable constituted also its mechanical strength. With the iron-wire spirally-covered cables, it was the reverse. The envelope of iron wires and hemp was the great cause of failure in deep sea cables; and when it was considered that this outer covering cost more money than the essential portions of the cable, it was time that some new system of construction should be introduced. He then referred to a compound of gutta percha, and said, that material, in the process of rolling, acquired a longitudinal fibre which gave it such strength that, when pulled in a longitudinal direction, it was impossible to break it without using great force, although in the transverse direction it could be torn with the greatest ease. If the insulator of cables were constructed of that material and in that manner, all the requisite longitudinal strength could be obtained, combined with every element of insulation. A coil which he had prepared for the proposed line from Toulon to Algiers, consisted only of the copper conductor, enclosed in about 90 films of this insulating material; and the facility of manufacture was such, that it could be rolled out at the rate of six miles an hour. In the core of the Atlantic cable, the great fault consisted in its having little or no longitudinal strength: a comparatively slight strain would start the core and spoil the insulation; whereas if the insulators had been constructed of the thin films, it would have supported 20 miles of cable over the stern of the ship, with a tensile strain of nearly 2 tons. In constructing the core of cables, he had for some time experienced considerable trouble, in consequence of the soldering of the joints of the copper conductor, which compelled him to stop the machinery for each joint, but by a new mode of constructing the conductor, this difficulty had been overcome. Instead of having a single conductor, he formed a conductor of small wires from 30 to 50 in number, according to the size of the conductor required; these were bound longitudinally together, and covered with a coating of collodion. He could manufacture six miles of that core per hour. He apprehended no difficulty with this cable in deep-sea submersion, and he would much prefer running down the Red Sea, and going from Aden to Bombay, instead of passing along the shore in the manner suggested. With reference to laying a cable across the Atlantic, he proposed to carry a line direct from Falmouth to Portland (U. S.), to be called the "London and New York direct line," avoiding all land lines through uncultivated countries, as also the complications caused by intermediate stations, as in the case of the Newfoundland line. Owing to the small size of the cable, he proposed that a vessel of the Cunard class should be brought alongside a wharf, when the cable could be paid into the ship as fast as it was made, thereby saving the expense and annoyance of transhipment. He believed they were on the eve of important changes in regard to telegraphy. The Balaklava and Varna line was laid and worked successfully, though coated with only an ordinary covering of gutta percha.

He had not as yet had any opportunity of laying this cable, but he had received several inquiries as to the method of constructing telegraph cables by means of tapes of india rubber, or gutta percha, or paraffin compound, from which it appeared that one important part of the construction was not sufficiently understood. In winding tapes of india rubber round wires in the manner usually adopted, no longitudinal strength was obtained, but when the tapes were applied in the mode proposed, under considerable tension, a different result ensued. It was to this particular process in the construction of telegraph cables to which he would particularly invite attention. Instead of winding the india rubber round the wire conductor, it was applied while under the greatest tension, and the thickness of material required for insulation was acquired by a series of films of extreme tenuity. When it was considered that a single film, or ribbon ·002 inch thick, would lift a weight of 25 lbs., it would easily be perceived what great longitudinal strength must result from a thick series of these films. His own experience went to show, that for the cores of telegraph cables, the insulating material could not be too hard, provided it was sufficiently flexible to resist, without injury, the effects of coiling, and of the rough handling to which telegraph cables were exposed. India rubber, vulcanized by the hot process, was not, from its pliability and softness at all temperatures, well adapted either for the insulating, or for the covering of telegraph cables, but if vulcanized by the cold process, it was rendered hard, and in this state it was well adapted for the outer covering of cables. Unvulcanized india rubber, from its electrical properties, and from its hard and tough nature, was an excellent material for insulating purposes. He confidently anticipated, that an unvulcanized india rubber cable constructed after this method could be successfully laid, and after submersion, would be found to last for many years, as it would possess all the requisite tensile strength, joined to the essential property of durability. After the insulator was formed in the manner described, the next process was to coat it with a compound, of india rubber and carbon, for protection, and this was cured or cold vulcanized, by passing the cable through a mixture of chloride of sulphur and bi-sulphate of carbon.

Mr. FOWLER, V.P., inquired what was the greatest length of wire which had been covered by this process, and if the insulation had been tested, and with what result?

Mr. MACINTOSH replied, that for telegraph purposes he had not coated more than six or seven yards of submarine cables, made expressly for testing purposes; but he had coated several hundred miles of small wires for land use. He was able to state that the insulating material had been tested by means of the best instruments that could be procured, and the entire accuracy of which could be relied upon. Samples had been tested by Professor Miller, Mr. Desmond Fitz-Gerald, and others. The results obtained, both with the material in bulk, and also in lengths of wire, showed, that whilst india rubber was about 35 per cent. superior in insulating properties to gutta percha, paraffin compound was about 35 per cent. better than india rubber. The reason why he had not made greater lengths of telegraph cables, was that his machinery was not suited to cover ordinary conductors, the wires of which constantly required soldering, and occasioned a stoppage of the machinery for each joint that was made. He had now perfected a mode of constructing wire conductors without soldering, and he was in a position to construct with facility any length of cable, and he hoped soon to be able to exhibit a specimen of his proposed Atlantic cable.

Mr. J. A. LONGRIDGE said, that after listening to the Paper and the discussion, he was convinced of the inadvisability of attempting to establish and maintain telegraphic communication through such a country, as that traversed by the telegraph which had been described. It had been admitted that that telegraph was in an extremely unsatisfactory state, and he thought, in traversing such a route as had been selected, there were inherent difficulties which it would be found impossible to remove; but he believed that in India, a successful line of telegraph could be maintained, and worked. He believed also, that the Persian Gulf telegraph would work satisfactorily, but he did not think the employment of European instrumentalists through such a country as that from Fao to Constantinople would be successful. He believed the best instrumentalists in the world, isolated in a country like that, would before long lose the energy which characterized them when they were appointed.

The next remedy suggested was to revert to submarine cables. He admitted that deep sea cables had to a great extent been failures, but shallow water cables had been almost equally wanting in success. It was only necessary to point to one or two, out of many. He took the last, and most successful one, viz., the cable between Malta and Alexandria, which, though commercially successful, yet as an engineering work was frequently failing; and it would be found that the failures were in inverse proportion to the depth of water in which the cables were laid. From Malta to Tripoli the water was of considerable depth; from Tripoli to Benghazi there was fair depth of water; but from thence to Alexandria might be regarded as shallow water, and it was in that section of the line that the failures had most frequently occurred. The future of submarine telegraphy depended upon deep sea cables. It was now eight years since he brought this subject before the Institution.[1] He had carefully considered it in the interim, and the conclusion to which he had arrived was, that there was no difficulty in laying deep sea cables, providing they were suitable for the depths in which they were to be laid. In the Paper referred to, the conclusion arrived at was, that it was necessary to have a cable of low specific gravity. It was then shown, that the strain on a cable ought never to exceed that which was due to the depth of water in which it was laid, or that which was equivalent to the weight of the length of the cable suspended over the ship's stern. It followed that if a cable approached the specific gravity of water, there could be no difficulty in submerging it. He did not think the reasoning on which that conviction was founded had ever been refuted. He believed, at the present day, the general opinion was in favour of light cables for deep water; and it was evident in the course adopted in the case of the greatest of all deep water cables—the Atlantic—that the advisers of that company had arrived at that conviction. But though a cable of low specific gravity had been adopted, yet he was sorry to see the way in which it had been done. In fact, a cable of high specific gravity had been manufactured, and then on the iron wire was placed a substance, or substances, which tended to reduce that specific gravity. It was stated that this coating was also for the purpose of preserving the wires from corrosion; but when once a cable was laid in deep water the iron wires were of no use, inasmuch as the raising of a cable from a depth of 2,000 fathoms was a mechanical problem impossible of solution. Therefore when a cable was to be laid in deep water, all thought of ever raising that cable from the bottom should be set aside, and every endeavour should be concentrated upon safely getting it there; and in order to accomplish that it was necessary to have a very light cable. In the cable adopted in the Atlantic experiment, the lightness was obtained by putting round the cable a material like hemp, which, while it gave a light specific gravity, involved the difficulty of enormous bulk, and made the laying of it dependent upon the employment of such a vessel as the 'Great Eastern.' He was quite convinced that a cable of $\frac{5}{8}$ths of an inch diameter could be made with precisely the same conducting power, and precisely the same insulation, and yet occupy only about one-fourth of the bulk of the Atlantic cable.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xvii., p. 221.

In order that a cable might be laid successfully, it was necessary that there should be no strain upon it, except that due simply to its sinking through the water; but in the apparatus generally adopted, there was a system of ponderous sheaves and breaks, the inertia of which had a serious effect upon the cable. In the records of the late Atlantic experiment, taking the last day's work, it was stated, that from 10·50 a.m. on August 1st to 7·50 on the 2nd—that was 21 hours—150 miles of cable were paid out, being at the rate of 7·14 miles per hour; and that the distance traversed by the ship from 9·50 a.m. on the 1st to 6·50 a.m. on August 2nd—also 21 hours—was precisely the same; consequently, there could be no doubt, that the last 150 miles of cable were laid without a particle of slack, but in a straight line from point to point.[1] The specific gravity of that cable would necessitate a strain of from 25 cwt. to 26 cwt. on the paying-out apparatus; and yet he was informed, that there was no weight whatever upon the breaks of the paying-out apparatus, and that for the last few days they ran entirely free. But it appeared that though the breaks ran free, yet for a great way the cable was laid without slack and with a tension of 25 cwt. That being the case, he could not but express an opinion, that the paying-out apparatus was not perfect, and was prejudicial to the laying of the cable. He heartily wished the Atlantic scheme success; but he thought he ought not to hesitate to give expression to these opinions, more especially as there was so much weight of authority on the other side. The public were told that everything had been done, that the ship was perfect, the paying-out apparatus perfect, and the cable itself perfect. He must say, he could not agree with those conclusions: if he did, he should give up all hope for the future of deep sea cables. He did not think either the construction of that, or of any other cable yet tried in deep waters, had been such as was calculated to insure success. As to the ultimate success of the operation he had no doubt. He believed, with a cable of light specific gravity, and with proper paying-out apparatus, it could be laid with the utmost success; and he would advocate, in the case of the Indian line, instead of short stations, a direct course from Suez to Aden, and thence to Bombay; and when that was effected, he apprehended there would be no hesitation in devoting a larger sum, for a line from Gibraltar to Sierra Leone, Ascension, St. Helena, Mauritius, and Seychelles, to Galle; thence again, a line to Singapore, and another to Australia. He believed, the day would come when that great line would be carried out with profit to the commercial community and to the public; but he protested against the doctrine, that the heavy iron wires were necessary as coverings for deep sea cables, inasmuch as he thought they were the source of all the evils that had befallen cables hitherto. He likewise protested against the doctrine, that shallow water cables were more likely to be maintained in order than perfectly-constructed deep sea cables.

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[1] After the close of the discussion, it was stated to Mr. Longridge by Mr. Clifford, that the above figures were incorrect, and that there was never less than 14 per cent. of slack paid out, and that the strain on the cable never exceeded 14 cwt. To this Mr. Longridge would reply, first, that the figures given by him were those published by the Secretary of the Atlantic Telegraph Company, and which had never been denied till they were shown to indicate the defective motion of the cable and the paying-out apparatus; and, secondly, that it was proved by Mr. Longridge and Mr. Brooks, and corroborated by the high authority of Mr. Woolhouse, F.R.A.S., that the indications of a dynamometer, such as that used, were quite fallacious under certain circumstances.—J. A. L.

MR. OWEN ROWLAND expressed his opinion, gathered from the views of persons resident on the spot, that it would be madness to attempt to carry out and maintain a line of telegraph through Turkish territory, where the power of the government was *nil*. He believed the proper route to be, an entirely submerged cable, through the Red Sea to Kurrachee. The public mind did not as yet appear to be satisfied with the prospects of telegraphy, as a source of profitable investment for money. The telegraph from Malta to Alexandria was paying, as was also the Persian Gulf line, and he believed most of the other submarine lines. He thought that deep sea cables, when successfully laid, would pay exceedingly well; but the difficulty was in submerging them. He had prepared a list of all the failures that had taken place, set out under the heads,—1st, the length of cable; 2nd, the places to which they were laid; 3rd, the makers of the cables; and 4th, the engineers and electricians employed. In the year 1859 he entered into the service of the Board of Trade, and conducted experiments upon various inventions relating to telegraphy, for upwards of eighteen months, including different insulating materials, and great lengths were tested by him to prove their insulating and inductive qualities. The Atlantic Telegraph Company, previous to the manufacture of their cable, invited all inventions to be sent in, for the purpose of being practically tested. After the authentic publication of results, the wires were disposed of, with the exception of certain lengths which were safely deposited under his care, on the premises of the Electric and International Telegraph Company. During the last three weeks he had re-tested those wires very carefully, and he found, that during the time the wires had been lying by, the insulating properties of the gutta percha had improved considerably. If the public had lost confidence in telegraphy through an apprehension of the failure of the materials, that apprehension was unfounded, inasmuch as he had practical proof, that the quality of gutta percha improved in water. The Government gutta percha wires showed an improvement in the insulation to the extent of no less than 45 per cent. He was well acquainted with all the insulating materials that had been introduced during the last twenty years, and the result of his experience, from every description of test applied,—chemically and electrically,—was, that if any description of solvent was employed in the manufacture, the advantage was only temporary, and as the solvent disappeared the insulation of the wires and the joints decreased in the same ratio. He had tested some hundreds of miles of the Atlantic cable, and some thousands of joints, and he confessed, he looked suspiciously upon them. He believed, looking at the subject of telegraphy generally, however it might be at present regarded as an investment, it would be useless to attempt to stop its progress.

Mr. THOMAS ALLAN said the Paper and the discussion opened up a question of immense importance. It was the problem of telegraphic communication between Great Britain and her colonies and dependencies. The discussion had gone to show very plainly, what progress had been made during the last seven, or eight years. As regarded communication with India, it might be said to have been, for practical purposes, a failure. By *The Times* of December 5, 1865, it would appear that the last telegram received from Bombay was dated November 25th, and from Calcutta November 23rd. If the line was carried out in a homogeneous chain, messages ought to reach Bombay in the course of a forenoon, whereas by the present fragmental system it was impossible to foresee what the results would be. He did not object to this state of things, because it would enforce the necessity of going back to first principles. With respect to the proposition to extend the telegraph system to Australia and China, unfortunately the Persian Gulf line, however excellent it might be physically, and however well it might do its work, was planted between two disorganizations which made it next to useless to the commercial community; and as such things could not be carried out without the "sinews of war," it was difficult to make people believe them to be a good investment for their money. As things now stood, he could not see the necessity for any immediate hurry to get to Australia and China. However well the line might be laid between Singapore and Australia, what would be the condition of the telegraph to this country? If so many days were occupied by a message from Bombay, what would it be from Sydney or Melbourne? Shallow water routes, and heavy, expensive cables had been advocated, even in short sections. That was contrary to the philosophy of the electric telegraph and to the political economy of a telegraphic communication from one distant point to another. It was self-evident, that to be done well, it must be done in long stretches, with few repeating stations, so as to secure greater rapidity of transmission, by which means the cost of telegrams would be reduced to a minimum and made advantageous to the consumer, for any trade that was not advantageous to the consumer would not be of much value to the investor. There was no use in subdividing a line into short sections with frequent stations planted in out-of-the-way places, costly to maintain, and which were suckers and not feeders to the main line. Some years ago it was proposed that a cable should be laid between this country and India, in lengths of 1,400 or 1,500 miles, going *viâ* Gibraltar, Malta, Alexandria and Aden to Bombay. By such a plan it was evident that something approaching to continuity and accuracy would be secured, and the errors from repetitions would be, to a great extent, avoided. Formerly between London and Glasgow there were five repetitions; now it was done in one circuit, and the accuracy was consequently increased. The great point was to carry out the communication by direct lines, and to have as few stations as possible, which would increase the accuracy and rapidity of transmission, reduce the tariff, and so be useful and valuable to the community at large, commercially and politically.

Captain SELWYN, R.N., said, with regard to what could and what could not be done in the future, he agreed with most of the general propositions laid down by Mr. Longridge; but there were two points on which he ventured to record his dissent. One was as to the curve of the cable, which Capt. Selwyn always conceived to be, where there was any slack whatever, an upward one; and the other was, as to the alleged impossibility of lifting a submerged cable from any great depth, whereas he would undertake to lift any cable capable of supporting twenty times its own weight in water 2 miles deep, provided it had not been left to decay. It seemed to him that the construction of cables had been hitherto erroneous, in consequence of the application alternately of deep sea cables to shallow water, and shallow water cables to the deep sea. It was well known now, that in shallow water certain mechanical forces, produced principally by currents, had to be encountered, which materially affected a cable lying on rocks, or hard ground, and by anchors of ships in certain localities, and there were also purely mechanical causes of decay and loss, by abrasion. There was one other point which should be attended to in considering the possible effect of currents, which was, the accumulation of seaweed round the cable, increasing its size and the surface against which the current operated. Under such conditions, it was evident that no cable could last long. With respect to the route spoken of to Australia, he might mention a fact perhaps not generally known. Those islands which appeared on the chart to be so closely connected as to offer a safe route, although there was only a small space of water between them to be overcome, yet, in proportion to the smallness of the space from one island to the other was the velocity of the current. Invariably the action on a cable was more to be feared in such situations and where coral rock prevailed. It would be madness, unless great commercial centres could be reached only by such means, to prefer such a place to the open sea, which presented no such dangers. If no other route could be taken, then heavy mailed cables must be employed. In the open sea there were totally different mechanical conditions to fulfil. Those were, first, the safe deposit of the cable from the ship. Having once found the bottom of the ocean, that bottom, like the chalk hills on the land, was covered with such an amount of dust and débris of shells, that by no possibility, except where recent volcanic action had taken place, could it be otherwise than level for all practical telegraphic purposes. The hollows, if any existed, would be rapidly filled up by the fine dust of minute shells, which was constantly being deposited. Therefore the safe laying of the cable, not its preservation afterwards, was the true source of anxiety. The question of paying-out seemed to be the most pressing of all. A cable weighing 8 tons to the mile, in water which did not give a depth of more than 100 fathoms, involved scarcely any difficulties in laying, except by its too rapid issue. So much had been said on the question of spiral wires outside deep sea cables, that he scarcely thought it necessary to repeat, that it had been long since shown, that spiral wires could not, under any possible conditions, protect from strain, straight lines in their centre, particularly where the core had a certain amount of compressibility. In the early days of ocean telegraphy he called attention to the fact, that in a four-strand rope the heart strand was always the first to break. That should have been sufficient to show, that the spiral did not protect the straight line. If a cable was hanging vertically, or in a long curve in the water, it untwisted on its upper portion, and twisted up again as the strain was removed on its lower portion; but that twisting up could not take place, without making kinks on the bottom, which all would admit were not desirable things to have in a cable. What then was the best mode in which to meet the amount of strain required to be borne by a deep sea cable in the act of submerging? There was no other way of protecting a straight line than by having a straighter one, if such a thing were possible; but the remedy practically consisted in having a straight line of a substance having a higher tensile strength. Whether that was to be effected by the use of fine steel wire, which gave an excess of strength over the same metal in the bar, as 150 tons to 56 tons, or by fibre, or by some other substance, it was clear, the straight line within must be protected, particularly if it was desired to lift the cable again; for, he presumed, with a proper paying-out apparatus, there ought to be no strain thrown upon the cable during the laying, of such violence as in the least to endanger its vitality. He submitted that cables properly constructed could be lifted at any time and at any depth, for the ocean's depths were nowhere, as was once supposed, unfathomable. To aid this, it was necessary that they should have accurate surveys of the bottom. The bed of the ocean was too generally assumed to be unchanging. He could state that he had indicated the position of a shoal in the middle of the Atlantic entirely through a consideration of the effects, in forming shoals, of the current of the Gulf Stream crossing to the Cape de Verde Islands, and meeting the Arctic current. Here would probably be found a bottom, on which a cable might be safely laid, and as safely recovered. Upon the question of insulating materials, he was strongly impressed in favour of the compound of india rubber and paraffin. He had seen it tested by competent electricians, though he believed no great quantity of cable had been made, and therefore, it had not yet been tried to any great extent. It deserved close investigation, in order to set at rest the doubts, which it was so easy to throw upon any new invention; for if it was really good, the price of cables would at once be enormously reduced. Hydrographers might in many ways give most valuable aid to ocean telegraphy. Sailors had never been unwilling to lend their assistance, and he hoped by the united efforts of the two professions, they might be able to carry out successfully, that which hitherto had been so great a difficulty.

Mr. C. W. Siemens had intended to enter into some explanations with regard to the electrical tests, and of the value of the different units, and the reason of their occurring in such enormous numbers; but owing to the length of the discussion, he would confine himself to some of the practical points, on which he wished to make a few observations. Both india rubber and gutta percha could be put upon the wire in such a perfect manner that, provided those materials were not tampered with by solvents or excessive heat, permanent insulation could be insured, which was, in the case of gutta percha, materially improved by great hydrostatic pressure at the bottom of the sea; therefore it was chiefly to the outer covering and to the laying of cables, that attention should be directed in order to find out where improvements could be made. He would lay stress upon one important fact with regard to deep, as well as to shallow water cables, namely, that a cable would only remain electrically in good condition, so long as the outer covering remained intact. He did not believe that a cable could be laid safely without some kind of outer sheathing. The accidents which had occurred to the last Atlantic cable showed, how necessary it was to have an outer sheathing which could not be pierced by pointed wires; but in adopting an outer sheathing, it ought to be a permanent one. It was maintained, in answer to this assertion, that when a cable was laid in deep water, it would probably last for years after the outer covering had decayed. But it was known practically, that cables had failed after the outer covering was gone. In the Red Sea the cable failed, and the Malta-Alexandria cable broke down, wherever oxidation had been most active, through the exposure of the iron-wire sheathing. But it had been asked, what forces were there to destroy a cable laid upon a smooth bottom? If the bottom could be supposed perfectly smooth and oozy, and if the cable was supposed to have sunk into the ooze equally throughout, then he could indeed find no reason for its failure after the iron had decayed. But was it reasonable to suppose the existence of such a bottom? Would it not be probable that a dead fish, or the bone even of a dead fish, falling on this soft bottom, would support the cable falling over it, which would be, for part of its weight, suspended at that point. The part most exposed at the point of suspension would be first attacked by the corrosive action of the salt water, and it was indeed a fact, that the iron wires of cables corroded away in points before the whole was materially affected.

Supposing the iron wire to be corroded away in a place of partial support, then the cable to the right and left of that place would naturally sink. Thus readjustment of the weight of the cable upon the bottom naturally took place at the expense of the part where the strength had gone, causing the insulated conductor to elongate and to break. He thought, therefore, the outer sheathing ought to be permanent, in order that the cable itself might be so. He had advocated for years a particular form of cable, made of hemp, laid longitudinally, and covered with a flexible armour of sheet copper. He had laid about 200 miles of that cable in different parts of the world, and he found it to be very permanent, where it was not broken by mechanical agencies. The specimen exhibited had been taken from a depth of 1,500 fathoms, after being a year submerged. It was quite intact, whereas the iron-covered shore end was much corroded. He mentioned that fact in answer to what had been observed as to the impossibility of picking up a cable from a great depth.

Mr. LONGRIDGE said his remark applied principally to the Atlantic cable. If the end could be recovered, the cable could be under-run; but with the end lost, to pick it up and raise it to the surface from a depth of 2,000 fathoms, he believed, was impossible.

Mr. SIEMENS agreed in that case with Mr. Longridge. Practically it was of the utmost importance that the cable should be smooth, so as to be suitable for being picked up, or under-run. A cable covered with hemp could only be got up at a slow rate, but a smooth cable would come up with very little resistance. With regard to the lines in India, it had been said that iron posts did not answer so well as wooden ones. He differed from that opinion, as he had put up above a thousand miles of land telegraph upon iron posts, with most satisfactory results. Of course better insulation was required with iron than with wood; and one of the great faults of insulators was, that they were generally put upon brackets, and the wire was either suspended on the top or by the side of them. That was an imperfect form of insulator, inasmuch as on a heavy rain falling upon the bracket, the spray rose into the cup and destroyed insulation during the rain. All wires should be suspended from the insulating cup, a system which he had followed for many years, in constructing his bell insulator with vulcanite stalk. With a properly insulated line, with a proper staff of electricians and with good instruments, there would be no difficulty in working through from London to Calcutta in the course of an hour. He had worked through from London to Omsk, in Siberia, without any hand transmission; there had been mechanical transmissions, but the moment the signal was given in London it was received in the middle of Siberia.

With regard to the messages arriving in a mutilated condition, he might state, that on the continent there were many through lines working with a mechanical transmitter, which might be used with advantage for these great lines. The message was put into type, passed through the instrument, and transmitted mechanically through the line; it was received in a printed form, according to the Morse alphabet, at the rate of from 60 words to 80 words per minute. With such a system, well organized, there would be no difficulty in keeping up an immediate communication with India; or if there was any difficulty in the way of such a system, it would arise from political causes.

Sir CHARLES BRIGHT, in reply, said, the first subject which had been touched upon in the discussion was that of the route, which of itself would have afforded material for much discussion. The Paper (he had thought since he wrote it), had been somewhat too large in its scope, and it might have been better if it had been limited to the line between India and England, instead of entering upon the subject of the extension of the system to China and Australia. Some speakers had advocated crossing the desert from Beyrout to Bagdad. If that were done, as Major Champain justly remarked, the Turks would be deprived of all interest in supporting such a line, because it would cut off the greater portion of their remuneration from it, and there would be great difficulty in maintaining a line of telegraph across the desert in that direction, owing to the independent and predatory character of the Arab population, over which the Turks were unable to exert any useful control. It had been proposed, in reference to the duplicate route by way of the Red Sea to Bombay, to take a deep sea line, direct from Muscat to Bombay, and to continue the line to Australia, by laying a deep sea line from Ceylon to Australia, thus relinquishing the idea of the importance of carrying the line in shoal water where practicable. In the present state of experience of the comparative merits of shallow lines and deep sea lines, he should prefer a shoal water cable, where repairs could be readily effected, even if the line were somewhat longer, than to run the risk of laying a deep sea line. He did not say that deep sea lines were not reliable, but that a shoal line with a fair bottom should always be taken, where practicable, in preference to a deep sea line.

With regard to the working of the line, since the Paper was read he had had an opportunity of hearing a good deal of the experience of various commercial circles, Chambers of Commerce, and merchants in different parts of the country. Only the previous day he was in Liverpool, when it was represented by the East India and China Association, that the evil had got to be so great, that merchants were compelled to abstain from using the line, in consequence of the grievous errors and delays, and it was hoped that the Government must at last see the necessity for taking strong measures, to correct the wretched working of the Turkish and inland Indian lines. That state of things need not exist, as was shown by the fact of Sir Charles Wood having lately received a message from Sattara, respecting the termination of the Bhootan affair, in ten hours and a half, and of a message having been recently received at Constantinople from Calcutta, in three hours and a half. That was sufficient to show, that there was no reason why these delays, which were the rule, and not the exception, should be suffered to continue. As regarded the insulating material of submarine cables, it was to be hoped that Mr. Macintosh would proceed with the construction of greater lengths of line than

6 yards, or 7 yards, so as to afford the means of testing the value of his insulator on a practical scale. There would, no doubt, be great improvements in all directions, in india rubber, paraffin, and all the compounds with gutta percha; but he must in fairness say, he had always found the Gutta Percha Company desirous of carrying out any improvement in insulation, whatever might be the material suggested. He had not desired to assume any credit to himself for the experiments on resistances, but to show the complete curve, not upon a small number of degrees, but upon a large scale resulting from an extensive series of experiments, accompanied by a formula capable of general application in the testing of cables. Mr. Siemens had alluded to the outer covering of cables, and it appeared to be generally admitted, that for shallow water cables at all events, the outer covering of bitumen and silica adopted in the Persian Gulf cable, was suited for the requirements of the case. For the large circumference of such a cable a cheap covering was required, as well as one that could be quickly and easily made, suited for coiling on board ship, and paying-out. There was no danger from heating, for the compound was applied by an elevator driven by the closing machine, so that when the latter stopped, the supply of the compound ceased. While yet in a plastic state it was passed between two rollers, and the exterior was thus rendered smooth and hard, before the cable was passed into the tank.

November 21 and 28, 1865.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

The discussion upon the Paper No. 1,135, on "The Telegraph to India," etc., was continued throughout both evenings, to the exclusion of any other subject.

December 5, 1865.

JOHN FOWLER, Vice-President,
in the Chair.

The following Candidates were balloted for and duly elected:—JAMES DANFORD BALDRY, WILLIAM COLE BAYLY, JAMES AUGUSTUS CALEY, JAMES CROSS, FREDERICK EAST, THOMAS

HARDINGE GOING, HUGH LEONARD, EDWARD ORPEN MORIARTY, PARKE NEVILLE, WILLIAM HENRY PRICE, CUBITT SPARKHALL RUNDLE, BERNHARD SCHMIDT, CHARLES TARRANT, CROMWELL FLEETWOOD VARLEY, and EDWARD WILSON, as Members; JOSEPH BRIERLEY, THOMAS BUCKHAM, SEYMOUR CLARKE, WILLIAM CLARKE, JOHN DICKSON DERRY, JOHN DUNNING, CORNELIUS WILLES EBORALL, JAMES GRIERSON, RICHARD HARRIS HILL, GEORGE WILLIAM HORN, Major JULIAN ST. JOHN HOVENDEN, R.E., FRANCIS KING, CONYERS KIRBY, WILLIAM LANG, Colonel WILLIAM MONTAGU SCOTT McMURDO, C.B., ROBERT MESSER, ROBERT MOSELEY, WILLIAM NEWMARCH, F.R.S., JEREMIAH RYAN, ARCHIBALD SCOTT, EDWARD RUSH TURNER, HOWARD UNWIN, LEVESON FRANCIS VERNON-HARCOURT, M.A., GEORGE AMBROSE WALLIS, and GEORGE WOOLCOTT, as Associates.

The discussion upon the Paper No. 1,135, on "The Telegraph to India," etc., occupied the whole of the evening, to the exclusion of any other subject.

December 12, 1865.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

No. 1,129.—"Experiments on the Strength of Cement, chiefly in reference to the Portland Cement used in the Southern Main Drainage Works."[1] By JOHN GRANT, M. Inst. C.E.

SINCE the formation of the Metropolitan Board of Works, about ten years ago, the great system of drainage for the metropolis, recently described in Mr. Bazalgette's Paper,[2] has been designed and executed. The Author, who superintended that portion of the scheme which lies south of the Thames, believes that the following description of the means adopted to insure the use of cement of the best quality only, in these works, may not be without benefit, or interest to the members.

Previous to 1859, Roman cement was, with few exceptions, the only cement used for the inverts of the London sewers; the arches being set in blue lias lime, and Portland cement scarcely ever tried. In view, however, of these large works, the Author, about the end of the year 1858, commenced an extensive series of experiments upon bricks, cements, and other materials. Portland cement had, in this country, been chiefly confined to ordinary building operations, such as external plastering, and to some harbour works, on the southern coast and in the Channel Islands, where it was mostly used in the form of concrete blocks.

In France, and in other parts of Europe, large harbour and dock works had been constructed with Portland cement, made in England, and the tests employed, which were generally of a searching, though in some respects tedious, character, no doubt prepared the principal manufacturers of this country for the production of a cement suitable for works like those then contemplated for the drainage of London.

As a preliminary step, for the purpose of experiments, applications for samples were made to the leading manufacturers of Portland cement, and Tables I., II., III., and IV. of the Appendix give the result of the tests to which they were subjected. The names of the makers of these earlier samples have been omitted, as it might be considered invidious to compare one producer with another, especially as some of the samples forwarded for experiment were, avowedly, specially prepared. Other specimens were subsequently obtained from various makers, in the ordinary way, without mentioning the purpose for which they were required; and the results obtained, though they widely disagreed, were sufficiently satisfactory to warrant the insertion of the following clause, in the specification for the Southern High Level Sewer (1859), being the first contract on the south side of the river Thames :—

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[1] The discussion upon this Paper extended over portions of four evenings, but an abstract of the whole is given consecutively.

[2] *Vide* Minutes of Proceedings Inst. C. E., vol. xxiv.

"83. The whole of the cement to be used in these works, and referred to in this specification, is to be Portland cement, of the very best quality, ground extremely fine, weighing not less than 110 lbs. to the striked bushel, and capable of maintaining a breaking weight of 400 lbs. on an area 1½ inch × 1½ inch equal to 2¼ square inches, seven days after being made in an iron mould, of the form and dimensions shown on drawing No. 1 (Plate 2), and immersed six of these days in water." The Board having adopted this test, attention was next turned to devising some safe and ready mode of practically applying it with accuracy. For this purpose, moulds were made of bell-metal, having a sectional area, at the breaking point, of 1½ inch × 1½ inch = 2¼ square inches, with templates of thin iron, exactly fitting the mould, so that, with the aid of a simple machine, the bricks could be pressed out, shortly after the mould had been filled. The machine devised for showing the tensile strain, was a lever balance (Plate 5), very accurately constructed by Mr. P. Adie (Assoc. Inst. C.E.). The whole apparatus was fixed in testing houses on the works, and access to these premises could only be obtained through the proper officers. The machines used for testing, have since, in several cases, been adopted by the manufacturers at their own works, an acknowledgment of the soundness of the principle, and of its adaptability to the requirements of this manufacture. No difficulty was experienced in training an ordinary workman to test the cement by means of these machines; and after using, during the last six years, more than 70,000 tons of Portland cement, which has been submitted to about 15,000 tests, it can be confidently asserted, that none of an inferior, or dangerous character has been employed, in any part of the works in question.

In the construction of branch sewers, it has, in many cases, been necessary to cut through main sewers, and specimens of the materials are submitted, to show the perfect adhesion between the bricks and the cement.

During the preliminary experiments, objection was taken to the standard then proposed, and afterwards adopted, and it was strongly urged, that a standard of about 300 lbs., instead of 400 lbs., would be found, in practice, to be the highest attainable. But, fortunately for the cement trade itself, not only was the higher standard established, but, in subsequent specifications, it was increased. After the first start, little difficulty was experienced in obtaining Portland cement of standard quality. A few of the earliest deliveries were rejected, but subsequently, the makers of them regained their position; and the Author feels bound to express his thanks to those who so materially assisted, by the excellence of their manufacture, in obtaining such satisfactory results. While aiming at a high quality of cement, the necessity of sufficiently remunerating the manufacturer, was not lost sight of; and, in the first schedule of prices, *2s. 3d.* per bushel was the price inserted. This, however, is much above its present market value.

Though the use of Portland cement had been comparatively limited, the extensive adoption of this material, in the construction of the metropolitan sewers, drew the attention of engineers and contractors to its value and importance; and it may be safely assumed that, during the progress of these works, double the quantity of this cement has been used in London which was ever employed, in any equal period, since its first introduction, or discovery.

Roman cement is, under certain conditions, useful, but in works of importance, even with the adoption of precautionary measures to insure purity and freshness, its strength is much inferior to Portland cement. Besides its inherently weaker character, Roman cement has the great practical disadvantage, of losing its strength by being kept long before use, or by being exposed to the air; whereas Portland cement improves by being kept and by exposure to the air, provided it be kept dry.

No reference will be made, in this Paper, to the chemical properties of Portland cement, or to any theories as to the admixture, in its manufacture, of one material with another, in various proportions. These points have already been so fully treated upon, by members of the Institution, and by different foreign authors, as to have rendered familiar, at least, the prominent features of limes and cements.

The manufacture of Portland cement is not one of complex character, although it requires the exercise of extreme care, in the admixture of its two simple and well-known ingredients, clay and chalk. This cement is almost solely manufactured on the rivers Thames and Medway, and the clay is obtained from the creeks and bays between Sheerness and Maidstone. Much care is required in the selection of the clay, so that it shall be as free from sand as possible; and the proportion in which it is used depends altogether on the quality of the chalk, with which it is to be incorporated. In the white chalk districts, the clay forms from 25 per cent. to 30 per cent. of the whole bulk, and in the grey chalk districts, the proportion of clay varies from 16 per cent. to 20 per cent. Both districts have contributed to the satisfactory results, recorded in the accompanying Tables.

Experience in the daily use of Portland cement has enabled the clerks of the works and others, to judge, generally by colour and by weight, of its quality; and many of the bricklayers who have been employed on these works, and who had previously a very imperfect acquaintance with this cement, or with its peculiar properties, have now acquired confidence and experience in using it, which will be valuable hereafter, on other works upon which they may be engaged. It is not to be expected that, in ordinary small building operations, the necessary testing, though simple and inexpensive, will be maintained. In such cases the precaution must be taken of employing respectable manufacturers, who have the means of thoroughly testing the cement made by them, and who can confidently guarantee its quality. If proper care had been exercised, so many buildings would not be seen disfigured, by the blowing, or cracking of the cement with which they are covered. In all works of magnitude, engineers and architects should insist upon the cement being thoroughly tested, before being used. To do so, no great expense need be incurred; for the first cost of one of the machines is about £50, and the annual charge for labour, about £80. The whole expense of testing the cement used in these works, which extend over a district eighteen miles in length, and cost upwards of £1,250,000, has only been about 5 farthings per ton of cement; an utterly insignificant cost, when compared with the great advantages gained, in quality, and in soundness of work.

It was at first intended, that the tests should be confined to the simple requirements of the works, and it was not contemplated further to extend the observations and experiments. The facilities, however, which were afforded for the successful investigation of so interesting and useful a subject, induced the Author, not only to keep an accurate record of all the ordinary tests, but to extend his inquiry into other points, the results of which are shown in No. XVI. and following Tables.

Although the testing apparatus will indicate the strength of the cements, it must not be inferred, that it renders unnecessary all supervision afterwards. Among the more important points requiring attention are, the quality of the sand to be mixed with the cement, and the thorough saturation of the bricks, so that, in setting the cement may not be robbed, by absorption, of the moisture necessary for its perfect hardening. Instances have occasionally occurred where, in consequence of negligence on the part of the workmen, imperfect adhesion of the cement to the bricks has resulted. Great care is also necessary to prevent any current of water from passing over the cement, or through the joints, during the process of setting; as this would wash away the soluble silicates, which form a necessary element in the cement. The drainage works were protected from this danger, by stoneware pipes laid under the invert of the sewer, so as to carry off the water while the brickwork was in progress. In concrete, this must be specially guarded against, although the risk would be much reduced by the use of a cement of less specific gravity, which would set more quickly. In some cases, even Roman cement could be advantageously employed, for such purposes.

Tables I., II., III., and IV., may be considered the first of the series, and their only value consists in showing, how precarious and irregular the quality of Portland cement was, at that time. Some of the irregularity in the results may be attributed to the imperfect apparatus, used at that early stage; but this was of course avoided subsequently by the adoption of the new apparatus.

Tables I., II., and III., show an average weight of 108·6 lbs. per bushel, and an average breaking, or tensile strain, varying from 75 lbs. to 719 lbs. on 2¼ square inches. The adoption of this particular size was, to some extent, obligatory, from its being the only known form of mould in use. It is intended, however, to substitute a mould, with a sectional area of 4 square inches (Plate 3), and of a somewhat different form.[1]

The importance of having the cement finely ground, was shown very early in these experiments; and there can be no doubt, that much of the difference in these first results is attributable to the several samples varying greatly in this respect. At the same time, it was also manifest, that the cement, when carefully moistened, and only supplied with sufficient water to reduce it to a state of paste, gave better results than when unduly charged with water. The best method for applying water, is by a perforated nozzle, at the end of a pipe, or watering-can. It should be stated that, in every case, the shape and sectional area of the mould were the same, viz., 1½ inch × 1½ inch = 2¼ square inches. Where not otherwise stated, the samples were immersed in water, from the time of setting to the time of testing; and the results are, as a rule, the average of ten tests. Whilst setting, each sample was numbered at both ends, and recorded in duplicate, in registers, of which the form is given in the Appendix.

The means adopted to obtain accurate results having been described, and reference having been made to the earlier of these, as set forth in Tables I. to IV., attention will now be drawn to Tables V. to XV. inclusive, which give the strength, as tested by tensile strain, of 1,369,210 bushels of the Portland cement used in the drainage works on the south side of the Thames, between the years 1859 and 1865.

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[1] Later experience has shown that the original size, with form slightly modified, is preferable.—J. G.

These tables, of which V. and VI. are summaries, give the names of the manufacturers, the quantity supplied by each, the weight per bushel, the average breaking weight, and the specified standard. The tests have been 11,587 in number, and the general results are, that the cement supplied to these works has weighed, on an average, 114·15 lbs. per bushel, and has borne a tensile strain of 606·8 lbs., equal to 270 lbs. per square inch; whilst the specifications required a weight of 110 lbs. per bushel, and a tensile strength of 400 lbs. in the first instance, and afterwards of 500 lbs. Thus, the cement has been 51½ per cent. above proof, in the first case, and 21 per cent. in the second.

Besides these daily tests of the strength of the cement supplied for the works, further experiments were made, on the strength of cement by itself, and with different proportions and different kinds of sand, at periods varying from one week to twelve months.

Table XVI. gives the results of 370 experiments with Portland cement, weighing 112 lbs. to the imperial bushel, gauged neat, and with different proportions of various kinds of sand. The neat cement, bore, at the end of a week 558·5 lbs.; at the end of twenty-eight days, 784·5 lbs.; at the end of six months, 960·8 lbs.; and at the end of twelve months, 1,009·8 lbs. Mixed with an equal proportion of clean Thames sand, the breaking weight, at the end of a week, was 190·7 lbs.; at twenty-eight days, 373·5 lbs.; at six months, 603·2 lbs.; and at twelve months, 724 lbs. It will be observed, that at the end of a week the strength is only 34·1 per cent. of neat cement; at the end of a month, 47·6 per cent.; at six months, 62·8 per cent.; and at twelve months, 71·7 per cent. When mixed with Thames sand, in the proportion of 1 of cement to 3 of sand, the breaking weights were, respectively, 62 lbs., 108 lbs., 308·1 lbs., and 371·1 lbs., at the end of a week, one month, six months, and twelve months; that is, 11·1, 13·8, 32·1, and 36·7 per cent. of the strength of neat cement. When mixed with the same sand, in the proportion of 1 to 4, the breaking weights, at one month, six months, and twelve months respectively, were 90·5 lbs., 149 lbs., 198·2 lbs.; or, 11·54, 15·5, and 19·62 per cent. of the strength of neat cement. When mixed with the same sand, in the proportion of 1 to 5, the breaking weights were 43 lbs. at one month, 122·5 lbs. at six months, and 204·4 lbs. at twelve months; or, 5·48, 12·75, and 20·24 per cent. of neat cement. The next column, gives the breaking weight of the same cement mixed with another sample of Thames sand, in equal proportions. The results were 213·8 lbs. at a week, 418 lbs. at a month, 614·5 lbs. at six months, and 757·9 lbs. at twelve months; or, from 2 per cent. to 12 per cent. more than in the first case. The next two columns give the breaking weight of the same cement, when mixed with very clean pit sand, taken from the excavations. These results were somewhat higher than with either of the samples of Thames sand, being, with a proportion of 1 to 1, 227·8 lbs. at a week, 423·1 lbs. at a month, 625·9 lbs. at six months, and 815·4 lbs. at twelve months. The last being 12·6 per cent. above the first, and 7·71 per cent. above the second sample of Thames sand. The next two columns give the breaking weight of the same cement, with an inferior, or loamy pit sand, in the proportion of 1 to 1. The strength, at a week, was 166·8 lbs., and at a month, 376·9 lbs.; the latter being very nearly the same as the first sample of Thames sand = 373·5 lbs. When mixed with 2 parts of sand, the breaking weight, at a month, was 251·5 lbs., or 11·4 per cent. above the first-mentioned Thames sand. The last two columns show the breaking weight of the same cement when mixed with an equal quantity of the last-mentioned pit sand, washed; the results being 224·9 lbs. at a week, and 364·9 lbs. at a month. The washing of the sand seems to add about 35 per cent. to the strength at the end of a week; but, at the end of a month, this experiment is not so satisfactory. With washed pit-sand, in the proportion of 1 of cement to 2 of sand, the breaking weight, at 28 days, was 330 lbs., or 46·2 per cent. above the first specimen of Thames sand, or 31·21 per cent. above the same sand, when not washed.

Table XVII. gives the results of 960 experiments as to the breaking weight of Portland cement weighing 112 lbs. to the bushel, gauged neat, and also, with different proportions of Thames, clean pit, and loamy sands. When gauged neat, the cement bore:—

	lbs.
1 week	445·0
1 month	679·9
3 months	877·9
6 „	978·7
9 „	995·9
12 „	1075·7

Thus, in three months, the cement bore about double the strain it did at the end of a week, and at the end of 12 months, 241·70 per cent., or, nearly twice and a half the strain that it bore at the end of a week. These results agree, in the main, with those of the last Table, although the cement seems to have been somewhat slower in setting, breaking at 445 lbs. against 558·5 lbs. at the end of a week; but overtaking the first set at the end of six months, and at twelve months being 1075·7 lbs. against 1009·8 lbs., or having 6·5 per cent. greater strength. The next five columns give the breaking weights of the same cement, mixed with clean, sharp Thames sand, in proportions varying from 1 to 1, to 1 to 5.

When mixed with an equal proportion of sand, the breaking weights are at—

	lbs.		Per cent. of the strength of neat Cement.
1 week	97·0	=	21·8
1 month	309·3	=	44·5
3 months	367·0	=	41·8
6 ,,	546·8	=	55·9
9 ,,	607·8	=	61·3
12 ,,	700·3	=	65·1

When mixed with twice the proportion of sand, the breaking weights are at—

	lbs.		Per cent. of the strength of neat Cement.
1 week	52·5	=	11·80
1 month	123·5	=	18·16
3 months	254·5	=	29·00
6 ,,	425·1	=	43·46
9 ,,	431·5	=	43·33
12 ,,	458·5	=	42·62

When mixed in the proportion of 1 of cement to 3 of sand, the breaking weights are at—

	lbs.		Per cent. of the strength of neat Cement.
1 week	27·0	=	6·07
1 month	58·0	=	8·53
3 months	135·5	=	15·43
6 ,,	232·4	=	23·74
12 ,,	320·6	=	29·90

When mixed in the proportion of 1 of cement to 4 of sand, the breaking weights are at—

	lbs.
1 month	32·5
3 months	109·0
6 ,,	157·0
12 ,,	221·6

When mixed in the proportion of 1 of cement to 5 of sand, the breaking weights are at—

	lbs.
1 month	21·0
3 months	88·5
6 „	95·5
12 „	122·3

The next five columns show the breaking weights of the same cement, mixed with similar proportions of clean pit sand, taken from the excavations. The strength is, in every case, much greater than in the corresponding columns just described, where Thames sand was used. The succeeding five columns, giving similar particulars with a loamy pit sand, correspond more with the first five, where Thames sand was used, and show the importance of attending to the quality of the sand, especially where the proportions of sand vary. Looking down the three columns which give the breaking weights, with equal proportions of cement and sand, it will be perceived, that the strength rapidly gains in proportion upon that of the neat cement. Thus, in the first case, that which was only 21·8 per cent. at the end of a week, and 45·5 per cent. at the end of a month, at the end of the year has increased to 65·1 per cent. of the strength of neat cement. With clean pit sand, the corresponding column for 1 to 1 shows that the gain is much greater, increasing from 34·2 per cent. at the end of a week, to 74·0 per cent. at the end of a year. Again, if the breaking weights at twelve months, in the three sets of columns for the proportions of cement to sand of 1 to 2, 1 to 3, and 1 to 4, are multiplied by 2, 3, and 4 respectively, on the average it will be found, that the normal strength of the neat cement (1075·7 lbs.) is, as nearly as possible, diluted in proportion to the quantity of sand, the average numbers being 1066·1 lbs., 1103·4 lbs., and 1044·8 lbs. This, however, does not hold good with the proportion of 5 of sand to 1 of cement, except where the sand is purest; the strength at the end of twelve months, multiplied as before by 5, being 611·5 for Thames sand, 1078 for clean pit sand, and 831 for loamy pit sand, against 1075·7, the normal strength of the neat cement.

The foregoing experiments, extending only to twelve months, still left some interesting points unsettled: as, for instance, the age at which cement, whether neat, or mixed with sand, ceases to increase in strength; the age at which the several compounds of cement and sand approach nearest to the normal strength of neat cement, or, in other words, obtain their maximum strength; also, the most economical proportion of cement and sand, with an assumed minimum strength. The last point has been approximately ascertained, by the Table just referred to, inasmuch as it has been shown, that with sand in the proportion of 2, 3, and 4 to 1 of cement, the sand simply acts as a diluting agent; but, with sand in the proportion of 5 to 1 of cement, any imperfection in the sand, materially affects the strength of the compound. Thus, it is only with clean pit sand, that the full strength of the cement is obtained; the strength, 215·6, multiplied by 5, gives 1078 lbs. against 1075·7 lbs., the strength of the neat cement.

With the view of ascertaining, if possible, the age at which cement, mixed neat, and with sand, attains its greatest strength, another series of 300 experiments, intended to extend over ten years, was commenced, but at present, only those for the first three years, 160 in number, can be given (Table XVIII.). The cement, in this case, weighed 123 lbs. per imperial bushel. The breaking weights of the neat cement are, at—

	lbs.
1 week	817·1
1 month	935·8
3 months	1055·9
6 „	1176·6
9 „	1219·5
12 „	1229·7
2 years	1324·9
3 „	1314·4

The same cement when mixed with an equal proportion of Thames sand broke at the following weights:—

	lbs.		Per cent. of neat Cement.
1 week	353·2	=	40·78
1 month	452·5	=	48·35
3 months	547·5	=	51·85
6 „	640·3	=	54·42
9 „	692·4	=	56·77
12 „	716·6	=	58·27
2 years	790·3	=	59·65
3 „	784·7	=	59·70

The proportionate strength of cement and sand increases, it will be perceived, between three months and twelve months, at the rate of 2 per cent. every three months, but in the course of the second year only 1·38 per cent. per annum. In the third year there is no increase.

Table XIX. gives the results of 225 experiments, made with cement gauged neat, and kept for periods, varying from seven days to twelve months, first, in water; secondly, out of water, in-doors; and thirdly, out of water, exposed to the action of the weather. At the end of twelve months, the results are respectively, as 1099, 827·4, and 719·6; that is to say, the cement which was kept out of water in-doors attained only 75·29 per cent. of the strength of that which was kept in water; while that which was out of water, and exposed out of doors, acquired only 65·48 per cent. As there are considerable variations in the apparent strength at different ages, if the averages are taken, they are as 100, 80·64, and 76·8. Cement allowed to set under water seems, from these experiments, to gain in strength from 24 per cent. to 30 per cent.

Tables XX. and XXI. give the relative strength of cement gauged with fresh water, and with salt water, at various ages, from a week to five months. The difference, though not very material, is in favour of salt water. This is satisfactory, as in the case of harbours, docks, and piers, where the water is either salt, or brackish, there need be no hesitation in using salt water, either in making Portland cement concrete, or in building.

Tables XXII. to XXVII. inclusive, show the results of 685 experiments made with Roman cement. The only inferences to be drawn from these are, that the best Roman cement is very inferior to Portland, especially when mixed with sand.

Table XXVIII. gives the strength of Keene's cement and Parian cement, in water and out of water, for periods varying from seven days to three months. At three months, the strength of Keene's cement in water, is 508·8 lbs.; out of water, 720·5 lbs.; or 41 per cent. more. Parian cement, in water, 521 lbs.; out of water, 853·7 lbs.; or 64 per cent. more.

Table XXIX. gives the strength of Medina cement at various periods, from seven days to two years, the increase being from 211 lbs. at seven days, to 476·9 lbs. in twelve months, and 276 lbs. in two years. There is a great falling off in the second year.

These three cements have only been used for internal architectural purposes.

Table XXX. gives the number of tons required to crush bricks made of Portland cement neat, and with five different proportions of sand at three, at six, and at nine months, at which different periods the strength of the neat cement bricks was 65 tons, 92 tons, and 102 tons respectively, or more than that of Staffordshire blue bricks. Bricks made of a mixture of sand with cement, in the proportions of 4 to 1, and 5 to 1 stand a pressure equal to the best stock bricks.

Tables XXXI.—XXXIV. give the results of about 300 experiments, on the strength of different kinds of bricks.

Table XXXV. shows the strength of blocks of Portland, Bramley Fall stone, and York stone landings, of the same size as an average brick. Portland stone, on its bed, bears a crushing weight of 47 tons, on an area of about 40 square inches, equal to 2,631 lbs. per inch; and against its bed it bears somewhat less. Bramley Fall, on its bed, bears 91⅓ tons, equal to 5,122 lbs. per square inch, or nearly double that of Portland; and against its bed it bears 52⅔ tons, or 2,953 lbs. per square inch.

The following is a recapitulation of the results of the tests and experiments shown in the annexed Tables, and of such facts as have come under observation:—

1st. The earlier experiments, made six years ago (Tables I. to IV.), gave, at the end of a month, a breaking weight, varying from 75 lbs. to 719 lbs. on an area of 2¼ square inches.

2nd. A minimum test of, at first 400 lbs., and afterwards of 500 lbs., was specified.

3rd. During six years, the average strength of 1,369,210 bushels used in the Southern Main Drainage Works has been 606·8 lbs. (Tables V. and VI.), being 52 per cent. above the standard first specified, and 21 per cent. above that subsequently adopted.

4th. The average weight per bushel has been 114·15 lbs., being 4·15 per cent. above the specified standard.

5th. Portland cement has been proved to be peculiarly suitable for hydraulic works, and may be procured in any quantity, and of the highest quality.

6th. Portland cement, if it be preserved from moisture, does not, like Roman cement, lose its strength by being kept in casks, or sacks, but rather improves by age; a great advantage in the case of cement which has to be exported.

7th. The longer it is in setting, the more its strength increases. (Tables XVIII. and XIX.)

8th. Neat cement is stronger than any admixture of it with sand.

9th. Cement mixed with an equal quantity of sand (as has been the case throughout the Southern Main Drainage Works), may be said to be, at the end of a year, approximately three-fourths of the strength of neat cement.

10th. Mixed with 2 parts of sand, it is half the strength of neat cement.

11th. With 3 parts of sand, the strength is a third of neat cement.

12th. With 4 parts of sand, the strength is a fourth of neat cement.

13th. With 5 parts of sand, the strength is about a sixth of neat cement. (Table XVII.)

14th. The cleaner and sharper the sand, the greater the strength.

15th. Very strong Portland cement is heavy, of a blue-grey colour, and sets slowly. Quick-setting cement has, generally, too large a proportion of clay in its composition, is brownish in colour, and turns out weak, if not useless.

16th. The stiffer the cement is gauged, that is, the less the amount of water used in working it up, the better.

17th. It is of the greatest importance, that the bricks, or stone, with which Portland cement is used, should be thoroughly soaked with water. If under water, in a quiescent state, the cement will be stronger than out of water. Table XIX. shows that cement kept in water was one-third stronger than that kept out.

18th. Blocks of brickwork, or concrete, made with Portland cement, if kept under water till required for use, would be much stronger than if kept dry.

19th. Salt water is as good for mixing with Portland cement as fresh water.

20th. Bricks made with neat Portland cement are as strong at from six months to nine months as the best quality of Staffordshire blue bricks, or similar blocks of Bramley Fall stone, or Yorkshire landings.

21st. Bricks made of 4 parts or 5 parts of sand to 1 part of Portland cement will bear a pressure equal to the best picked stocks.

22nd. Portland cement concrete, made in the proportions of 1 of cement to 8 of ballast, in some cases, and of 1 to 6 in others, has been extensively used for the foundations of the river-wall, piers of reservoir, and foundations generally, at Crossness and Deptford, with the most perfect success; and it is believed that it might be much more extensively used as a substitute for brickwork, or masonry, wherever skilled labour, stone, or bricks are scarce, and foundations are wanted with the least expenditure of time or money.

23rd. Wherever concrete is used under water, care must be taken that the water is still; as otherwise, a current, whether natural, or caused by pumping, will carry away the cement and leave only the clean ballast.

24th. Roman cement, though about two-thirds the cost of Portland, is only about one-third its strength, and is therefore double the cost, measured by strength.

25th. Roman cement is very ill adapted for being mixed with sand.

In conclusion, whilst recommending Portland cement as the best article of the kind that can be used by the Engineer, or the Architect, the Author would warn any one against its use, who is not prepared to take the trouble or incur the trifling expense of testing it; as if manufactured with improper proportions of its constituents—chalk and clay—or improperly burnt, it may do more mischief than the poorest lime.

Further experiments are desirable, on the strength of adhesion between bricks and cement, under varying circumstances; on the limit to the increase of strength with age; on the relative strength of concrete made with various proportions of cement and ballast; and on the use of cement in very hot climates, where probably extra care will be required in preserving the cement from damp, and in keeping it cool, until the process of setting has been completed. On these and other points, it is trusted that all who have the opportunity will make a record of their observations, for presentation to the Institution. Great credit is due to those manufacturers who have produced the high quality of cement (from 20 per cent. to 50 per cent. above the specified strength), shown in Table VI. The Author desires to acknowledge the obligation he is under to Mr. H. Reid, of Elmley, Kent, whose early education and experience, as an Engineer, led him to appreciate the value of Portland cement for engineering works, and whose suggestions and assistance, in the first stages of this inquiry, were of the most important and valuable character.

The communication is accompanied by an extensive series of Tables, which will be found in the Appendix, and by numerous diagrams, from which Plates 2 to 8 have been compiled.

APPENDIX.

TABLE I.

ABSTRACT of 70 Experiments with Portland Cement, mixed neat, and immersed in water, for seven and fourteen days. January, 1859.

MANUFACTURER.	Weight per Bushel.	In Moulds 7 Days.		In Moulds 14 Days.	
		No. of Experiments.	Average Breaking Tests.[1]	No. of Experiments.	Average Breaking Tests.[1]
	lbs.		lbs.		lbs.
A	113	1	663	2	691
B	109	8	335	4	525
C	112	1	518	2	502
D	112	5	397	5	485
	103	7	373	8	464
E	110	6	371	4	465
F	110	1	299	2	355
G	109	1	299	2	334
H	106	6	294	3	313
I	83	2	215	..	..
Average .	106·7	38	354·61	32	462·5

TABLE II.

TABLE of the results of 200 Experiments with Portland Cement, mixed neat, and immersed in water for seven days, made between 12th April and 4th July, 1859.

MANUFACTURER.	Weight per Bushel.	Breaking Tests.[1]		
		Minimum.	Maximum.	Average.
	lbs.	lbs.	lbs.	lbs.
K	120	313	719	526·75
C	116	327	509	417·50
A	105	327	481	395·90
G	109	187	472	370·15
D	110	187	478	360·40
J	106	187	439	328·15
B	105	131	383	318·90
H	107	75	540	315·80
E	102	75	404	251·70
F	96	175	318	237·50
Average .	107·6	198·4	474·3	352·27

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[1] Sectional area, 2·25 square inches.

THE STRENGTH OF CEMENT

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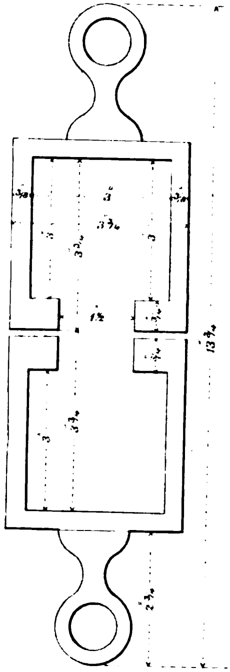
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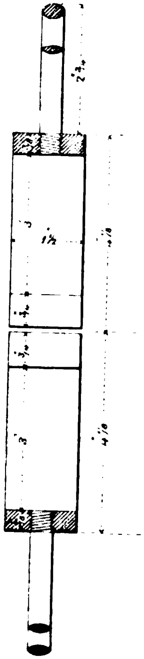
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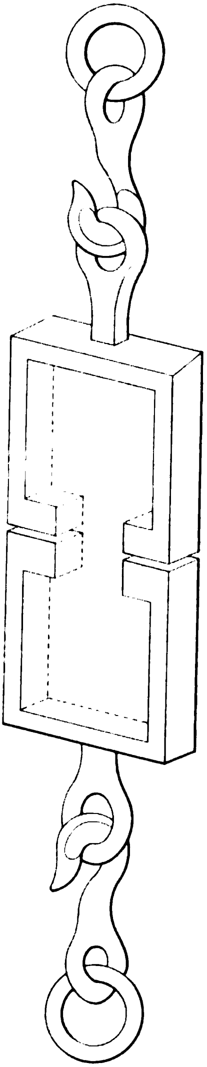

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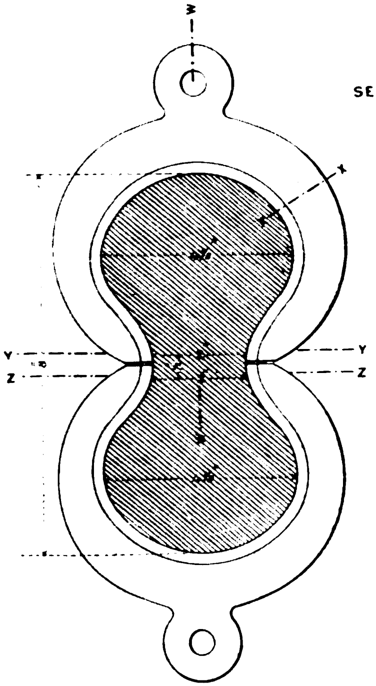

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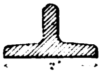

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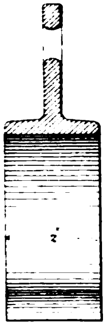

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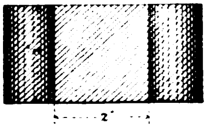

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THE STRENGTH OF CEMENT

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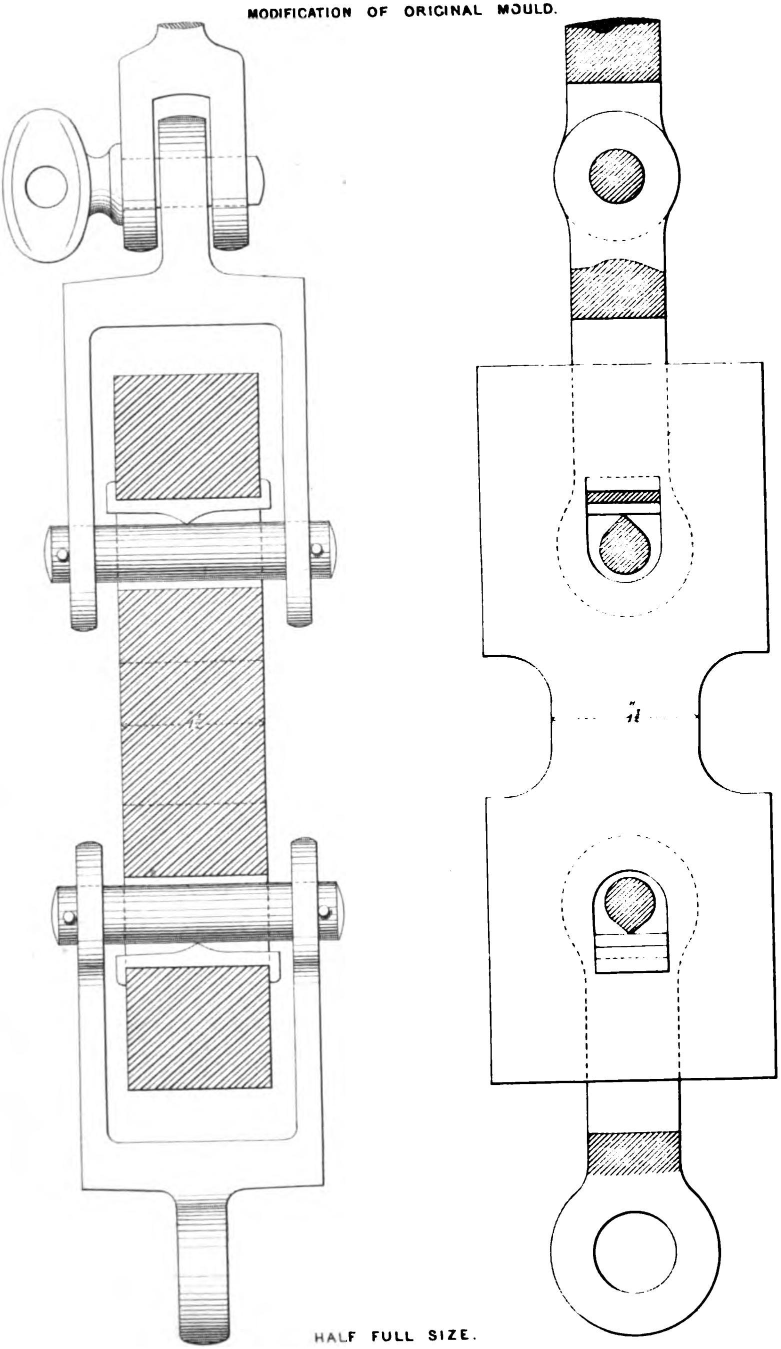

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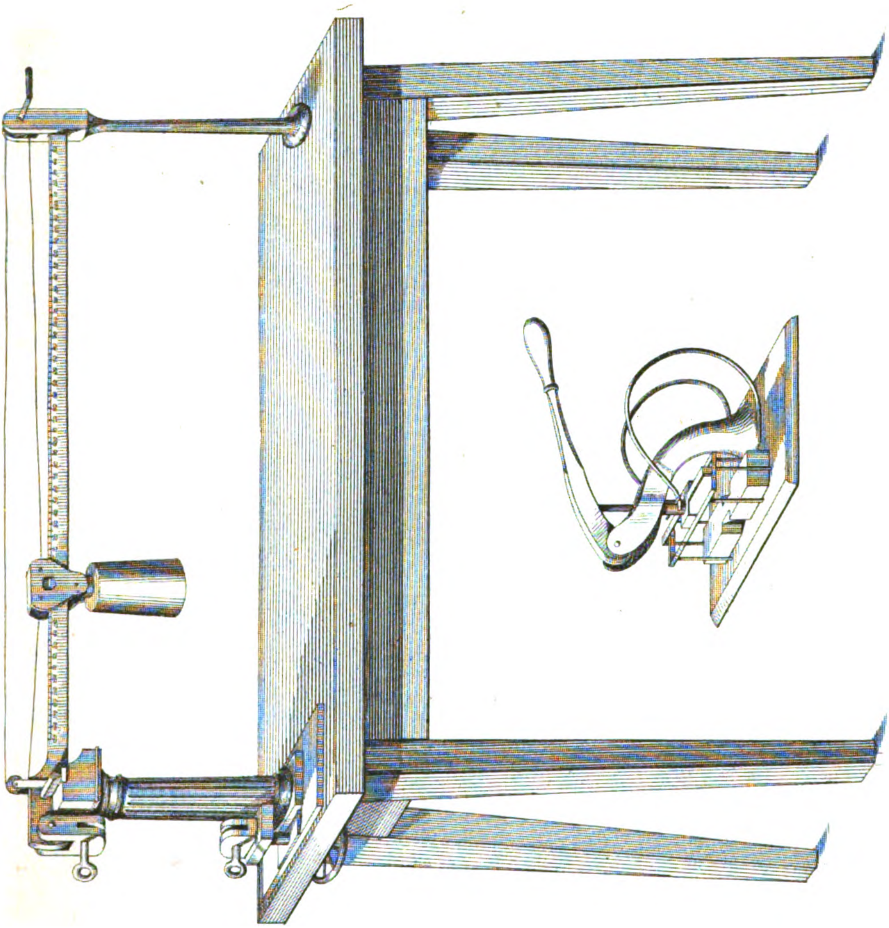
PLATE 5. VOL. XXV.

TESTING MACHINE.



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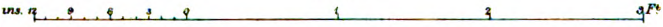

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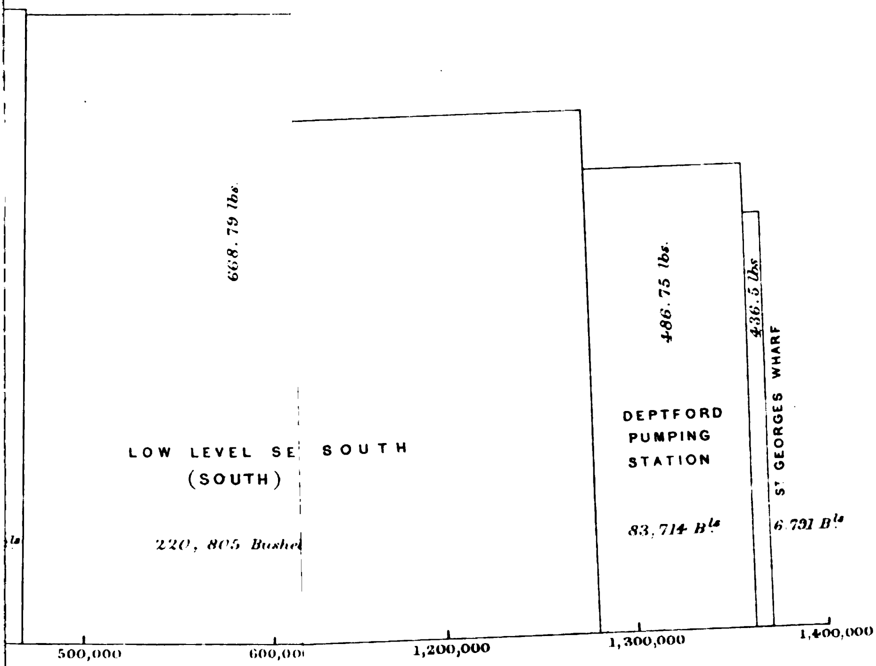

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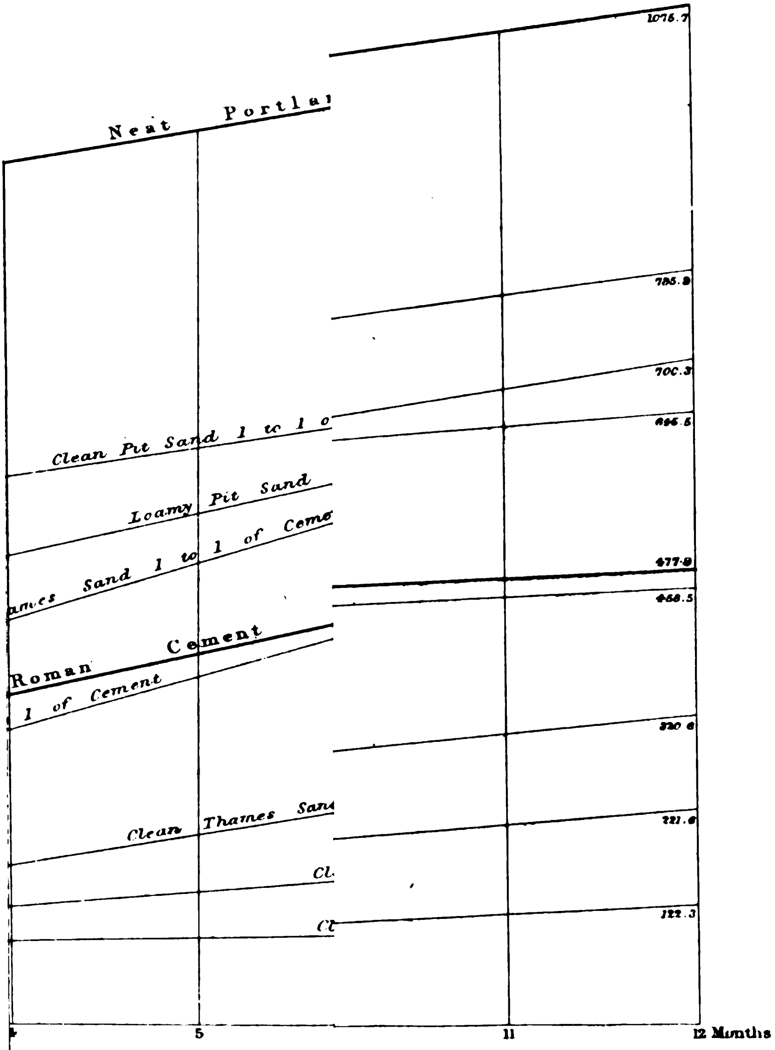

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DIAGRAM TO ILLUSTRATE TABLE

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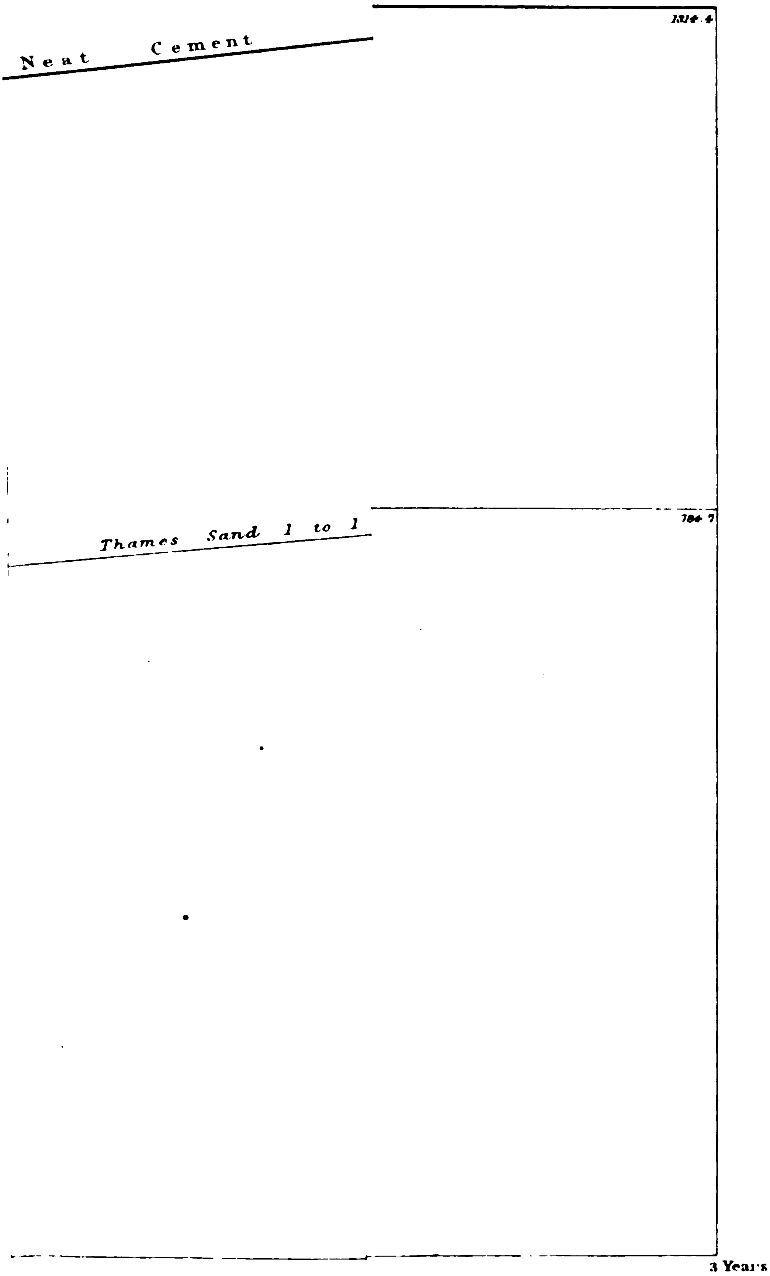

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TABLE III.

TABLE of the Results of 17 Experiments with Portland Cement, mixed neat, and immersed in water for seven days. March, 1859.

MANUFACTURER.	No. of Experiments.	Weight per Bushel.	Breaking Tests.[1]		
			Minimum.	Maximum.	Average.
		lbs.	lbs.	lbs.	lbs.
K	2	120	635	719	677·0
L	2	104	509	546	527·5
D	3	112	453	551	499·6
A	2	113	383	489	436·0
C	2	112	383	467	425·0
B	2	109	405	419	412·0
G	2	114	306	327	315·5
E	2	110	299	327	313·0
Average .	17	111·75	421	484	453·68

TABLE IV.

TABLE of the Results of 15 Experiments with Portland Cement, mixed with an equal proportion of sand, and immersed in water for seven days. 3rd to 10th March, 1859.

MANUFACTURER.	No. of Experiments.	Weight per Bushel.	Breaking Tests.[1]		
			Minimum.	Maximum.	Average.
		lbs.	lbs.	lbs.	lbs.
A	3	113	387	398	392·0
C	3	112	173	187	182·3
E	3	110	159	198	177·3
B	3	109	145	173	163·6
D	3	112	117	131	121·6
Average .	15	111·2	195·4	217·4	207·4

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[1] Sectional area, 2·25 square inches.

TABLE V.
METROPOLITAN MAIN DRAINAGE.
CONTRACTS ON THE SOUTH SIDE.
SUMMARY OF TABLES VII. to XV. inclusive.
PORTLAND CEMENT, Seven Day Tests, from 1859 to 1865.

NAME OF CONTRACT.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.[3]	Specified Standard Test.[3]
		lbs.		lbs.	lbs.
Southern High-level Sewer[2] (VII.)	148,728	119·04	1,532	558·07	400
St. George's Wharf (VIII.) . .	6,791	113·28	222	436·56	..
Southern Outfall Sewer[1] (IX.)	391,405	110·96	3,350	550·62	..
Deptford Pumping Station (X.)	83,714	111·63	740	486·75	..
Southwark Improvement (XI.) .	39,212	117·39	600	672·14	400 & 500
Southern High-level Extensions (XII.)	50,443	113·81	780	626·81	400
Bermondsey Branch (XIII.) .	78,492	119·07	690	688·27	500
Southern Outfall Works[1] (XIV.)	349,620	113·57	2,097	692·99	..
Southern Low-level Sewer[1] (XV.)	220,805	114·15	1,576	668·79	..
Generally . . .	1,369,210	114·15	11,587	606·80	..

TABLE VI.
METROPOLITAN MAIN DRAINAGE.
CONTRACTS ON THE SOUTH SIDE.
SUMMARY OF TABLES VII. to XV. inclusive.
PORTLAND CEMENT, Seven Day Tests, from 1859 to 1865.

NAMES OF MANUFACTURERS AND AGENTS.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests[3]	Specified Standard Test.[3]
		lbs.		lbs.	lbs.
Mr. Robins	128,467	119·43	1,423	670·67	400
Burham Brick and Cement Company (Mr. Webster)[1] .	938,322	112·89	7,023	631·09	400 & 500
Messrs. Lee and Co.[2] . . .	99,450	120·03	962	612·85	400
Messrs. E. Bow and Co. (Agents)	1,000	..	10	546·80	..
Messrs. J. B. White & Brothers	34,430	109·13	327	544·18	..
Mr. Hilton	27,788	114·17	510	511·01	..
Messrs. Knight and Co. . .	69,358	112·66	574	500·53	..
Mr. Smeed	44,241	111·85	423	452·36	..
Mr. Wood (Agent)	3,600	107·83	102	444·50	..
Messrs. Cubitt and Co. . . .	..	112·00	6	409·11	..
Mr. Buckwell (Agent) . . .	1,400	100·00	3	408·50	..
Messrs. Fletcher & Co. (Agents)	20,154	118·00	179	394·03	..
Messrs. Francis Brothers . .	1,000	105·66	31	328·22	..
Mr. Tatham (Agent) . . .	..	106·00	14	184·71	..
Generally . . .	1,369,210	114·15	11,587	606·80	..

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[1] Mr. Webster was the Contractor for the erection of two-thirds of the works embraced in Tables V. and VI.

[2] Wm. Lee, Esq., M.P., was the Contractor for the Southern High-level Sewer.

[3] Sectional area, 2·25 square inches.

TABLE VII.
METROPOLITAN MAIN DRAINAGE.
SOUTHERN HIGH-LEVEL SEWER.
Messrs. LEE and Co., Contractors.
SUMMARY of PORTLAND CEMENT, Seven Day Tests, from 1859 to 1862.

NAME OF MANUFACTURER.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.*
		lbs.		lbs.
Messrs. Lee and Co. . . .	99,300	120·06	952	614·66
Messrs. E. Bow and Co. . .	1,000	..	10	546·80
Mr. Robins	19,300	120·87	183	544·32
Messrs. Knight and Co. . .	6,338	118·50	75	541·13
Messrs. Fletcher, Lark, and Co.	18,154	118·50	159	515·15
Mr. Wood	3,600	107·83	102	444·50
Mr. Hilton	36	..	6	426·00
Messrs. Francis Brothers . .	1,000	105·66	31	328·22
Mr. Tatham	..	106·00	14	184·71
Generally . . .	148,728	119·04	1,532	558·07

* Specified standard, 400 lbs.

TABLE VIII.
METROPOLITAN MAIN DRAINAGE.
ST. GEORGE'S WHARF CONTRACT.
Messrs. JOHN AIRD and SON, Contractors.
SUMMARY of PORTLAND CEMENT, Seven Day Tests, from 1860 to 1862.

NAME OF MANUFACTURER.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.*
		lbs.		lbs.
Mr. Hilton	6,500	113·64	202	440·00
Messrs. Knight and Co. . .	96	105·66	12	408·08
Messrs. J. B. White & Brothers	195	119·00	8	392·50
Total	6,791	113·28	222	436·56

* Specified standard, 400 lbs. Sectional area, 2·25 square inches.

TABLE IX.

METROPOLITAN MAIN DRAINAGE.

SOUTHERN OUTFALL SEWER.

Mr. WILLIAM WEBSTER, Contractor.

SUMMARY of PORTLAND CEMENT, Seven Day Tests, from 1860 to 1862.

NAME OF MANUFACTURER.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.*
		lbs.		lbs.
Burham Brick and Cement Company (Mr. Webster)	317,671	111·51	2,726	564·14
Messrs. J. B. White and Brothers	26,280	108·85	179	521·38
Messrs. Knight and Co.	31,888	110·92	247	510·52
Mr. Smeed	10,766	112·18	153	476·65
Messrs. Cubitt and Co.	..	112·18	6	409·11
Mr. Buckwell	1,400	100·00	3	408·50
Mr. Hilton	1,400	111·00	16	402·30
Messrs. Fletcher, Lark, and Co.	2,000	111·00	20	223·10
Generally	391,405	110·96	3,350	550·62

* Specified standard, 400 lbs.

TABLE X.

METROPOLITAN MAIN DRAINAGE.

DEPTFORD PUMPING STATION AND GAS WORKS.

Messrs. JOHN AIRD and SON, Contractors.

SUMMARY of PORTLAND CEMENT, Seven Day Tests, from 1860 to 1862.

NAME OF MANUFACTURER.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.*
		lbs.		lbs.
Mr. Robins	1,200	118·00	10	691·40
Mr. Hilton	17,952	115·18	210	545·28
Messrs. Knight and Co.	30,937	109·55	240	482·03
Messrs. Lee and Co.	150	118·00	10	440·90
Mr. Smeed	33,475	111·66	270	438·62
Generally	83,714	111·63	740	486·75

* Specified standard, 400 lbs. Sectional area, 2·25 square inches.

Table XI.

METROPOLITAN MAIN DRAINAGE.

Southwark and Westminster Communication (Southwark Street and Subway).

Messrs. Downs and Pearson, Contractors.

Summary of Portland Cement, Seven Day Tests, from 1862 to 1863.

Name of Manufacturer.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.*
		lbs.		lbs.
Mr. Robins	26,438	120·12	430	700·64
Burham Brick and Cement Company (Mr. Webster) .	4,720	122·66	30	684·20
Messrs. J. B. White & Brothers	8,054	108·07	140	582·00
Generally . . .	39,212	117·39	600	672·14

* Specified standards, 400 lbs. and 500 lbs.

Table XII.

METROPOLITAN MAIN DRAINAGE.

Southern High-level Extensions (Dulwich, Brixton, and Denmark-hill Contracts).

Messrs. Pearson, Webster, and Dowell, Contractors.

Summary of Portland Cement, Seven Day Tests, from 1862 to 1863.

Name of Manufacturer.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.*
		lbs.		lbs.
Mr. Robins	3,037	114·59	110	674·95
Mr. Hilton	1,200	117·71	60	644·28
Burham Brick and Cement Company (Mr. Webster). .	46,206	113·11	610	616·54
Generally . . .	50,443	113·81	780	626·81

* Specified standards, 400 lbs. and 500 lbs.

Table XIII.

METROPOLITAN MAIN DRAINAGE.

Low-level Sewer (Bermondsey Branch).

Messrs. John Aird and Son, Contractors.

Summary of Portland Cement, Seven Day Tests, from 1862 to 1863.

Name of Manufacturer.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.*
		lbs.		lbs.
Mr. Robins	78,492	119·07	690	688·27

* Specified standard, 500 lbs. Sectional area, 2·25 square inches.

TABLE XIV.

METROPOLITAN MAIN DRAINAGE.

SOUTHERN OUTFALL WORKS.

Mr. WILLIAM WEBSTER, Contractor.

SUMMARY of PORTLAND CEMENT, Seven Day Tests, for 1862—1864.

NAME OF MANUFACTURER.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.*
		lbs.		lbs.
Burham Brick and Cement Company (Mr. Webster).	349,620	113·57	2,097	692·99

* Specified standard, 500 lbs.

TABLE XV.

METROPOLITAN MAIN DRAINAGE.

SOUTHERN LOW-LEVEL SEWER.

Mr. WILLIAM WEBSTER, Contractor.

SUMMARY of PORTLAND CEMENT, Seven Day Tests, for 1864 and 1865.

NAME OF MANUFACTURER.	Quantity in Bushels.	Average Weight per Bushel.	Number of Tests.	Average Breaking Tests.*
		lbs.		lbs.
Burham Brick and Cement Company (Mr. Webster)	220,105	114·15	1,560	669·52
Mr. Hilton	700	114·00	16	598·44
Generally . . .	220,805	114·15	1,576	668·79

* Specified standard, 500 lbs. Sectional area, 2·25 square inches.

TABLE XVI.

TABLE of the Results of 370 Experiments with Portland Cement, weighing 112 lbs to the Imperial Bushel, gauged neat, and with different proportions of various kinds of Sand, showing the Breaking Weight on a sectional Area of 2·25 Square Inches. 1861 and 1862.

AGE.	Neat Cement. Breaking Weight in	The same Cement and Thames Sand from Deptford Works in the proportion of					Thames Sand from Southern Outfall Sewer.	Clean Pit Sand.		Inferior, or Loamy Pit Sand.		Last kind of Sand, Washed.	
		1 to 1	1 to 2	1 to 3	1 to 4	1 to 5	1 to 1	1 to 1	1 to 2	1 to 1	1 to 2	1 to 1	1 to 2
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
7 Days . .	558·5	190·7	..	62·0	..	..	213·8	227·8	185·5	166·8	..	224·9	..
28 ditto . .	784·5	373·5	225·7	108·0	90·5	43·0	418·0	423·1	..	376·9	251·5	364·9	330·0
3 Months .	..	..	..	..	..	116·0	..	..	..	..	..	..	..
6 ditto . .	960·8	603·2	395·7	308·1	149·0	122·5	614·5	625·9	..	..	..	..	..
9 ditto . .	..	..	..	..	..	..	..	..	..	..	..	..	..
12 ditto . .	1009·8	724·0	483·4	371·1	198·2	204·4	757·9	815·4	..	..	..	..	..

TABLE XVII.

TABLE of the Results of 960 Experiments with Portland Cement, weighing 112 lbs. to the Imperial Bushel, gauged neat, and with different proportions of various kinds of Sand, showing the Breaking Weight on a Sectional Area of 2·25 Square Inches. 1862 and 1863.

AGE AND TIME OF IMMERSION IN WATER.	Cement Neat.	Clean Thames Sand.					Clean Pit Sand.					Loamy Pit Sand.				
		1 to 1	1 to 2	1 to 3	1 to 4	1 to 5	1 to 1	1 to 2	1 to 3	1 to 4	1 to 5	1 to 1	1 to 2	1 to 3	1 to 4	1 to 5
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1 Week	445·0	97·0	52·5	27·0	..	..	152·0	64·5	44·5	22·0	..	114·2	53·0	21·0	..	..
1 Month . . .	679·9	309·3	123·5	58·0	32·5	21·0	326·5	166·5	91·5	71·5	49·0	274·7	130·5	68·0	60·5	31·5
3 Months . . .	877·9	367·0	254·5	135·5	109·0	88·5	549·6	451·9	305·3	153·0	123·5	448·3	354·0	149·0	118·5	78·5
6 ditto	978·7	546·8	425·1	232·4	157·0	95·5	639·2	497·9	304·0	275·6	218·8	586·5	415·6	274·2	225·5	141·0
9 ditto	995·9	607·8	431·5	..	..	..	718·7	594·4	383·6	..	..	600·1	516·8	321·3	226·7	154·8
12 ditto	1075·7	700·3	458·5	320·6	221·6	122·3	795·9	607·5	424·4	317·6	215·6	645·5	533·2	358·4	244·4	166·2

TABLE XVIII.

TABLE of the Results of 160 Experiments with Portland Cement, weighing 123 lbs. to the Imperial Bushel, gauged neat, and with an equal proportion of clean Thames Sand, showing the Breaking Weight on a Sectional Area of 2·25 Square Inches.

These form the first portion of a Series intended to extend over 10 Years. The whole of the Specimens were kept in Water from the time of their being made till the time of Testing, 1863 and 1866.

AGE.	Neat Cement.	1 of Cement to 1 of Sand.
	Average Breaking Test of 10 Experiments.	Average Breaking Test of 10 Experiments.
	lbs.	lbs.
7 Days	817·1	353·2
1 Month	935·8	452·5
3 Months	1055·9	547·5
6 ditto	1176·6	640·3
9 ditto	1219·5	692·4
12 ditto	1229·7	716·6
2 Years	1324·9	790·3
3 ditto	1314·4	784·7

TABLE XIX.

TABLE of the Results of 225 Experiments with Portland Cement, weighing 109 lbs. to the Imperial Bushel, gauged neat, and kept—1st, in Water in Testing-house; 2nd, out of Water in Testing-house; and 3rd, out of Water on Roof of Testing-house, exposed to the action of the Weather. August, 1863, to September, 1864.

AGE.	Average Breaking Tests of Five Experiments.[1]		
	First.	Second.	Third.
	lbs.	lbs.	lbs.
7 Days	767·6	511·2	522·8
14 ditto	810·6	558·4	627·8
21 ditto	812·4	698·0	708·2
28 ditto	886·4	705·6	636·8
2 Months	881·0	877·0	594·0
3 ditto	952·0	612·8	671·0
4 ditto	968·6	774·6	814·8
5 ditto	993·0	786·6	783·2
6 ditto	1033·4	761·4	783·4
7 ditto	986·6	756·0	901·0
8 ditto	941·0	878·0	814·8
9 ditto	1048·6	845·8	714·0
10 ditto	1037·0	994·0	786·6
11 ditto	1039·4	909·6	876·0
12 ditto	1099·0	827·4	719·6
Total	14256·6	11496·4	10954·0

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[1] Sectional area, 2·25 square inches.

TABLE XX.

TABLE of the Results of 33 Experiments with Portland Cement, weighing 117 lbs. to the Imperial Bushel, mixed with Fresh and Salt Water from Sheerness. 1863 and 1864.

Sectional area, 2·25 square inches.

AGE OF SPECIMENS IMMERSED IN WATER.	Fresh Water.	Salt Water.
	Average Breaking Tests.	Average Breaking Tests.
	lbs.	lbs.
7 Days	738·2	891·00
14 ditto	..	938·66
21 ditto	..	973·50
28 ditto	..	940·40

TABLE XXI.

TABLE of the Results of 151 Experiments with Portland Cement, weighing 121 lbs. to the Imperial Bushel, gauged with Fresh and Salt Water. 1864.

Sectional area, 2·25 square inches.

AGE OF SPECIMENS IMMERSED IN WATER.	Fresh Water.	Salt Water.
	Average Breaking Tests.	Average Breaking Tests.
	lbs.	lbs.
7 Days	922·0	942·86
14 ditto	1062·6	1056·60
21 ditto	1138·5	1147·70
28 ditto	1123·9	1203·30
2 Months . . .	1175·5	1341·00
3 ditto	1256·9	1368·60
4 ditto	1320·7	1464·00
5 ditto	1327·16	1353·00
Total . . .	9327·26	9877·06

TABLE XXII.

TABLE of the Results of 5 Experiments with Roman Cement, mixed neat, and immersed in water for seven days. February, 1859.

MANUFACTURER.	Number of Specimens.	Weight per Bushel.	Breaking Tests. Sectional area, 2 25 square inches.		
			Minimum.	Maximum.	Average.
		lbs.	lbs.	lbs.	lbs.
Mr. Oldham . .	2	82·0	271	275	273·0
Mr. E. Cleaver. .	3	79·0	131	138	133·3
Average . .	5	80·5	201	206·5	189·2

TABLE XXIII.

TABLE of the Results of 60 Experiments with Roman Cement, weighing 82 lbs. to the Imperial Bushel, gauged neat, and immersed in water, showing the Breaking Weight on a Sectional Area of 2·25 Square Inches. 1862 and 1863.

AGE.	Roman Cement.
	Average Breaking Tests of 10 Experiments.
	lbs.
7 Days	77·5
28 ditto	94·5
3 Months	114·5
6 ditto	90·5
9 ditto	85·5
12 ditto	104·3

TABLE XXIV.

TABLE of the Results of 110 Experiments with Roman Cement and Sand. Manufactured by Messrs. COLES, SHADBOLT, & Co. March, 1864.

AGE AND TIME IMMERSED IN WATER.	Neat Cement.			1 Cement to 1 Sand.			1 Cement to 2 Sand.			1 Cement to 3 Sand.			Remarks.
	Minimum Breaking Test.	Maximum Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
7 Days	180[1]	213[1]	201·83[1]	60	110	79	..	..	..	..	..	..	[1] Four of these would not bear the minimum strain.
14 ditto	130	215	168·00	..	..	..	10	35	18·5				
21 ditto	200[2]	253[2]	221·14[2]	..	..	..	..	..	..	10	45	17·5	[2] Three of these would not bear the minimum strain.
1 Month . . .	173[3]	283[3]	243·33[3]	..	..	..	..	..	..	..	..	..	[3] One of these would not bear the minimum strain.
3 Months . . .	238	400	329·60										
6 ditto	252	408	376·80										
9 ditto	78	306	167·80										
12 ditto	137	428	323·80										

TABLE XXV.

TABLE of the Results of 90 Experiments with Roman Cement and Sand. Manufactured by Messrs. J. B. WHITE and Brothers. March, 1864. Sectional area, 2 25 square inches.

AGE AND TIME IMMERSED IN WATER.	Neat Cement.			1 Cement to 1 Sand.		
	Minimum Breaking Test.	Maximum Breaking Test.	Average Breaking Test.	Minimum Breaking Test.	Maximum Breaking Test.	Average Breaking Test.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
7 Days	170	240	202·0	15	45	26·5
14 ditto	160	190	173·0	..	..	..
21 ditto	170	205	186·5	..	..	..
1 Month	246	291	260·3	..	..	..
3 Months	307	344	322·5	..	..	..
6 ditto	442	502	472·7	..	..	..
9 ditto	313	520	471·1	..	..	..
12 ditto	596	680	643·1	..	..	..

TABLE XXVI.

TABLE of the Results of 250 Experiments with Roman Cement and Sand. Manufactured by Mr. JAMES R. BLASHFIELD. March, 1864.
Sectional area, 2·25 square inches.

AGE AND TIME IMMERSED IN WATER.	Neat Cement.			1 to 1 Sand.			1 to 2 Sand.			1 to 3 Sand.			1 to 4 Sand.			1 to 5 Sand.		
	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
7 Days. . .	95	150	120·5	35	75	47·5	5[1]	10[1]	7·0[1]	10[2]	10[2]	10·0[2]	10[3]	10[3]	10[3]	[5]	[5]	[5]
14 ditto . . .	145	209	169·9	53	79	65·6	22	57	42·8	8[4]	30[4]	19·2[4]	[5]	[5]	[5]			
21 ditto . . .	128	171	155·2	54	89	74·2	37	56	45·9	8	25	17·4						
1 Month . .	343	378	358·2	75	91	81·2	8	54	41·9	[5]	[5]	[5]						
3 Months . .	160	274	220·4	32	160	121·9	72[6]	126[6]	91·75[6]				40[7]	54[7]	45·5	29[8]	48[8]	37·71[8]
6 ditto . . .	227	300	252·5	296	337	314·3	..	..	..	..	..	..	..	..	..	..	..	..
9 ditto . . .	169	300	251·5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
12 ditto . . .	216	300	268·5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

[1] Five of these would not bear the minimum strain.
[2] Eight ditto.
[3] Eight ditto.
[4] Five ditto.
[5] Five ditto.
[6] Two ditto.
[7] Six ditto.
[8] Three ditto.

TABLE XXVII.

TABLE of the Results of 170 Experiments with Roman Cement and Sand. Manufactured by Messrs. LARK and PARROCK. March, 1864. Sectional area, 2·25 square inches.

AGE AND TIME IMMERSED IN WATER.	Neat Cement.			1 to 1 Sand.			1 to 2 Sand.			1 to 3 Sand.			1 to 4 Sand.			1 to 5 Sand.		
	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.	Min. Breaking Test.	Max. Breaking Test.	Average Breaking Test.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
7 Days . .	110	160	133·0	47	90	78·0	24	43	30·6	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]
14 ditto . . .	115	160	136·0	70	96	83·0	8	70	35·1	13	32	25·4						
21 ditto . . .	170	220	180·6	84	134	110·6	40	63	52·5	3[2]	6[2]	4·25[2]						
1 Month . .	183	251	216·5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
3 Months . .	257	334	302·7	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
6 ditto . . .	414	462	438·2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
9 ditto . . .	430	515	454·3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
12 ditto . . .	436	510	477·9	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
24 ditto . . .	444	550	518·0	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

[1] Would not bear the minimum strain.

[2] Six of these would not bear the minimum strain.

TABLE XXVIII.

TABLE of the Results of 120 Experiments with Keene's Cement, manufactured by Messrs. J. B. WHITE and BROTHERS; and Parian Cement, manufactured by Messrs. FRANCIS and SONS.
In Water in Testing-house, and out of Water in Testing-house, September, 1864.
Sectional area, 2·25 square inches.

AGE AND TIME IMMERSED IN WATER.	Keene's Cement.		Parian Cement.	
	In Water.	Out of Water.	In Water.	Out of Water.
	Average Breaking Test.	Average Breaking Test.	Average Breaking Test.	Average Breaking Test.
	lbs.	lbs.	lbs.	lbs.
7 Days	543·9	546·0	595·1	642·3
14 ditto	486·9	585·8	600·8	671·2
21 ditto	503·0	579·4	543·4	696·6
1 Month	490·2	584·2	544·3	746·7
2 Months	454·7	648·4	500·7	725·6
3 ditto	508·8	720·5	521·1	853·7

TABLE XXIX.

TABLE of the Results of 110 Experiments with Medina Cement and Sand.
Manufactured by Messrs. FRANCIS BROTHERS, 1864.
Sectional area, 2·25 square inches.

AGE AND TIME IMMERSED IN WATER.	Neat Cement.			1 Cement to 1 Sand.		
	Minimum Breaking Test.	Maximum Breaking Test.	Average Breaking Test.	Minimum Breaking Test.	Maximum Breaking Test.	Average Breaking Test.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
7 Days	83	100	92·1	..	..	..
ditto (2nd Series) .	195	235	211·0	41	63	49
14 Days	238	335	303·4	..	..	..
21 ditto	274	332	298·0	..	..	..
1 Month	210	346	306·0	..	..	..
3 Months . . .	420	468	448·8	..	..	..
6 ditto	376	438	412·4	..	..	..
9 ditto	438	507	457 2	..	..	..
12 ditto	456	527	476·9	..	..	..
2 Years	235	328	276	..	..	..

TABLE XXX.

TABLE of 178 Experiments on the Compression of Portland Cement Bricks.

Size 9 × 4·25 × 2·75 = 105·18 Cubic Inches; and exposed to Pressure 9 × 4·25 = 38·25 Square Inches. 1860 and 1861.

DESCRIPTION OF BRICKS.	Pressure when Specimen first showed signs of giving.			Pressure when Specimen finally crushed.			Remarks.
	Min. in Tons.	Max. in Tons.	Average in Tons.	Min. in Tons.	Max. in Tons.	Average in Tons.	
Neat Portland Cement	26·0	56·0	42·00	56·1	77·8	64·81	Made 3 Months.
1 Portland Cement to 1 Pit Sand. . .	14·0	35·0	29·24	34·6	46·9	42·53	
ditto . . . . . 2 ditto . . .	18·0	30·0	25·50	28·5	39·6	34·22	
ditto . . . . . 3 ditto . . .	13·5	24·5	19·99	20·4	27·0	24·52	
ditto . . . . . 4 ditto . . .	12·5	24·0	20·62	20·0	25·8	22·73	
ditto . . . . . 5 ditto . . .	0·9	16·0	10·29	11·7	19·2	16·37	
Neat Portland Cement	32·0	82·1	58·35	79·1	100·0	92·01	Made 6 Months.
1 Portland Cement to 1 Sand	16·2	55·1	32·82	54 2	66·1	59·39	
ditto . . . . . 2 ditto	10·2	49·4	24·80	35·0	57·3	47·00	
ditto . . . . . 3 ditto	10·1	40·0	19·42	32·1	43·1	36·81	
ditto . . . . . 4 ditto	8·0	14·2	10·13	27·3	44·2	30·68	
ditto . . . . . 5 ditto	8·0	19·0	11·91	21·8	31·8	26·29	
Neat Portland Cement	5·0	67·0	37·00	92·8	110·2	102·19	Made 9 Months.
1 Portland Cement to 1 Pit Sand. . .	44·4	76·1	64·40	65·1	85·3	77·88	
ditto . . . . . 2 ditto . . .	35·0	65·1	51·13	47·4	73·1	62·28	
ditto . . . . . 3 ditto . . .	16·2	41·0	33·25	34·1	46·3	40·87	
ditto . . . . . 4 ditto . . .	12·1	33·2	25·38	32·0	42·0	37·71	
ditto . . . . . 5 ditto . . .	10·0	26·2	19·40	24·0	38·2	28·66	

TABLE XXXI.

TABLE of 173 Experiments on the Compression of Bricks. 1863.

MANUFACTURER.	Description of Bricks.	No. of Specimens.	Weight of Specimens.	Contents of Specimens.		Dimensions of Specimens.			Pressure when Specimen first showed signs of giving.			Pressure when Specimen finally crushed.			Remarks.
				Cubical Contents.	Area exposed to pressure.	Lgth.	Bdth.	Thickness.	Min.	Max.	Average.	Min.	Max.	Average.	
			lbs.	Inches.	Inches.	In.	In.	In.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	
Mr. Harrison . . .	. . . .	5		103·73	37·72	8·88	4·25	2·75	13·10	28·20	15·900	62·0	83·2	68·15	Used on Bermondsey Branch.
	Gault Bricks . .	5	..	101·26	37·18	8·75	..	..	3·2	39·00	13·380	28·0	46·3	37·90	ditto.
	ditto . . .	5							6·5	20·2	12·120	29·2	36·0	32·38	ditto Frogs filled with Portland Cement.
Messrs. Allan, Sudbury	Brimstone, Suffolks	4	..	108·94	41·58	9·00	4·62	2·62	2·0	6·4	4·475	23·2	40·0	31·75	Deptford Pumping Station.
ditto	ditto . . .	4	..	..	..	..	..	.	4·4	33·6	17·100	40·2	54·0	48·45	ditto.
ditto	ditto . . .	10	6·8	111·10	41·34	9·06	4·56	2·69	1·0	8·0	5·100	25·0	37·0	31·00	Used on the Southern Outfall Contract.
ditto	Best Whites . .	10	6·6	89·99	41·90	9·19	..	2·62	1·0	9·0	5·100	16.0	27·0	19·60	ditto.
ditto	No. 3 Suffolks .	10	6·4	112·64	41·91	9·06	4·63	2·69	1·0	8·0	4·000	15·0	24·0	19·10	ditto.
Mr. Salters, Chilton .	Best Whites . .	10	6·3	104·44	40·76	9·19	4·38	2·56	2·0	10·0	5·300	19·0	36·0	25·90	ditto.
ditto	No. 2 Suffolks .	10	7·1	109·26	41·62	9·25	4·50	2·63	1·0	12·0	6·600	24·0	41·0	33·20	ditto.
Mr. Webster, Burham .	Gault Wire Cut No. 2 . . .	10	5·4	80·56	34.50	8·63	4·00	2·63	1·0	10·0	6·400	10·0	50·0	32·90	ditto.
ditto	ditto Pressed No. 1 . .	10	6·1	98·47	36·64	8·75	4·19	2·69	1·0	18·0	7·400	31·0	45·0	36·80	ditto.
Mr. Betts, Aylesford .	ditto. . . .	10	6·4	99·42	36·11	8·63	..	2·75	2·0	14·0	7·300	24·0	69·0	32·40	ditto.
Mr. Stares, Fareham .	Best Reds . .	10	6·3	94·82	36·13	8·50	4·25	2·62	1·0	15·0	8·420	19·0	37·0	26·10	ditto.
ditto	Best Rubbers .	10	8·8	145·83	49·64	10·19	4·88	2·94	1·0	3·0	1·400	11·0	21·0	15·70	ditto.
Mr. Pearson, Stourbridge	Best Firebricks .	10	7·3	101·62	39·66	8·94	4·44	2·56	3·0	25·0	15·800	56·0	71·0	62·80	ditto.
Mr. Ambrose, Colchester	No. 2 Salmon .	10	6·5	97·53	41·34	9·19	4·50	2·63	1·0	16·0	8·900	26·0	45·0	36·70	ditto.
Messrs. Knight, Woodbridge	No. 2 Suffolks .	10	6·1	99·45	38·81	9·00	4·31	2·56	5·0	14·0	8·800	33·0	42·0	37·30	ditto.
Mr. Smeed, Sittingbourne	Good Stocks . .	10	5·3	90·88	36·35	8·81	4·13	2·50	1·0	11·0	5·700	26·0	46·0	33·90	ditto.
Mr. Gilbert, Tipton . .	Best Blue . . .	10	8·0	94·33	37·73	8·75	4·31	2·50	5·0	75·0	21·600	52·0	*100·0	*95·20	ditto.

Those marked * withstood the utmost pressure of the Press.

TABLE XXXII.

TABLE of 82 Experiments on the Compression of Bricks. 1859 and 1860.

MANUFACTURER.	Description of Bricks.	No. of Specimens.	Contents of Specimens.		Dimensions of Specimens.			Pressure when Specimen first showed signs of giving.			Pressure when Specimen finally crushed.			Remarks.
			Cubical Contents.	Area exposed to Pressure.	Lngth.	Brdth.	Thickness.	Minimum.	Maximum.	Average.	Minimum.	Maximum.	Average.	
			In.	In.	In.	In.	In.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	
Messrs. Platt Bros.	. .	1	113·66	39·33	9·0	4·37	2·89	5·0	5·0	5·00	40·0	40·0	40·00	From Hartford Iron Works, Oldham.
ditto . . .	. .	1						40·0	40·0	40·00	45·2	45·2	45·20	ditto Frogs filled with dry Cement.
Mr. W. Webster, Burham.	Gault Bricks . .	5	111·37	40·50	..	4·5	2·75	5·0	11·0	7·46	14·0	20·1	17·26	Used on Low Level, Bermondsey Branch.
ditto	ditto . . .	5						13·3	19·0	16·46	27·2	33·4	30·48	ditto The Frogs of these Bricks were filled with Cement.
ditto	No. 1 Gault pressed Bricks.	10	105·30	..	..	..	2·60	4·6	15·0	9·10	36·0	55·6	48·00	Used for face-work, Church Street, Deptford. Frogs filled with Cement.
ditto	ditto . . .	10						5·0	18·0	8·76	28·2	42·6	32·70	Used for face-work, Church Street.
ditto	Wire Cut . . .	10	101·25	..	..	..	2·50	1·0	36·2	10·42	46·0	73·8	60·78	Used at Deptford Pumping Station.
ditto	Shippers' Stocks .	10						1·5	13·2	4·88	25·2	37·4	32·72	ditto.
ditto	ditto . . .	10						1·0	27·2	8·08	37·8	55·6	39·63	ditto; and Frogs filled with Cement.
Mr. Betts, Aylesford	Gault, pressed Bricks	10	91·13	..	..	..	2·25	3·5	11·6	8·46	25·6	50·4	35·22	Used on the Bermondsey Branch.
ditto . . .	ditto . . .	10						3·1	17·4	10·77	27·6	48·0	36·64	ditto; Frogs filled with Cement.

TABLE XXXIII.

ABSTRACT of 38 Experiments on the strength of various kinds of Bricks, &c. 1859 and 1860.

DATE.	Name of Maker.	Description of Bricks.	No. of Experiments.	Length.	Breadth.	Thickness.	Superficial Area.	Weight of Brick.	Minimum.	Maximum.	Total crushing Power. Average.	Crushing power per Square Inch.
				Inches.	Inches.	Inches.	Inches.	lbs. oz.	Tons.	Tons.	Tons.	lbs.
1859. May 28th	Mr. Gilbert . .	Blue Brick	1	9·00	3·1	4·2	27·90	..	..	..	50·00	4,014
,,	,, ,,	,, ...	1	8·75	6·0	4·2	52·50	..	..	..	75·00	3,200
,,	,, Cliff . . .	Fireclay Brick . . .	1	8·50	4·1	2·5	34·85	..	..	..	{65·62 {37·50	4,218 2,401
,,	,, Platt . . .	Red, Machine Brick . .	1	9·00	4·20	2·8	37·80	..	..	..	28·12	1,667
,,	,, ,,	,, ,, . .	1	9·10	2·85	4·1	25·93	..	..	..	18·75	1,619
Nov. 8th	,, Aylesford.		5	..	..	..	..	..	35·0	53	43·00	..
,,	,, Eastwoods. .		5	9·00	4·0	3·0	36·00	..	13·5	27	18·90	1,176
Aug. 9th	,, Taylor. . .	Blue Brick	5	9·00	4·32	3·0	38·88	..	63·0	90	50·60	2,915
,,	,, Gilbert . .	,, ...	2	8·60	4·08	2·88	35·09	..	72·0	78	75·00	4,759
,,	,, Cliff, Wortley Works, Leeds	,, ...	1	8·52	4·08	2·76	34·76	..	72·0	72	72·00	4,639
1860. March	,, Helling . .	Clay Bricks	3	8·75	4·30	3·10	37·63	7·9	24·0	27	26·00	1,574
,,	,,	Out of Norwood Tunnel, pressed Bricks . .	1	9·30	4·60	3·0	42·78	8·15	36·0	36	36·00	1,885
,,	,,		2	8·75	4·30	3·1	37·63	8·4	45·0	56	50·50	3,033
,,	,,	,, ,,	2	8·75	4·5	3·1	39·38	7·11	27·0	30	28·50	1,618
,,	,,	,, ,,	2	9·25	4·3	2·9	39·78	8·8	34·0	35	34·50	1,942
,,	,,	,, ,,	1	8·90	4·3	3·0	38·27	7·2	10·0	10	10·00	585
,,	,,	,, ,,	1	8·60	4·25	3·0	36·55	8·4	27·0	27	27·00	1,654
,,	,,	,, ,,	3	8·90	4·25	2·6	37·82	4 15	37·0	52	42·00	2,487

Table XXXIV.

TEN EXPERIMENTS MADE AT CROSSNESS PUMPING STATION.

Gisborne's Exbury Bricks—No. 1. January 12th, 1864.

Description of Brick.	Number of Specimens.	Size.			Cracked.			Crushed.			Area.	Cubical Contents.	Pressure per Square Inch.	Pressure per Cubic Inch.
		Length.	Breadth.	Depth.	Min.	Max.	Average	Min.	Max.	Average				
		inches.	inches.	inches.	tons.	tons.	tons.	tons.	tons.	tons.	inches.	inches.	lbs.	lbs.
No. 1 Exbury's Best	4	8·875	4·25	2·75	20	23	21·00	24	33	28·5	37·73	85·75	1,692	743
Second Quality . .	2	. .	. .	. .	22	22	22·00	28	30	29·0	. .	. .	1,722	757
Third ditto . . .	3	8·500	4·125	2·625	4	16	11·33	27	30	29·0	35·06	92·04	1·853	706
Unburnt Brick . .	1	8·875	4·375	2·875	1	1	1·00	9	9	9·0	38·83	111·63	0·519	180

Table XXXV.

Table of 21 Experiments on small Blocks of Stone, of the dimensions of an average Brick, with Frogs sunk therein. 1864.

Description of Stone Experimented on.	Weight when Cracking first took place.			Weight when Stone was Crushed.			Weight.	Size in Inches.			Area.	Cubical Contents	Crushing Power per Sq. Inch.
	Min.	Max.	Average	Min.	Max.	Average							
	tons.	tons.	tons.	tons.	tons.	tons.	lbs.				inches.	inches.	lbs.
Portland stone on the Bed	10	12	11·00	46	48	47·00	9	8·875	0·45	2·75	39·94	109·83	2,631
Portland against the Bed	7	10	8·33	38	38	42·66	10						2,393
Bramley Fall on the Bed	8	25	14·33	84	98	91·33	. .						5,122
Bramley Fall against the Bed	9	12	9·66	47	57	52·66	. .						2,953
Yorkshire Landing on the Bed	20	28	2·33	88[1]	100[1]	96·00[1]	. .						5,384
Yorkshire Landing against the Bed . .	17	28	21·66	100[2]	100[2]	100·00[2]	. .	8·75	4·375	2·75	38·28	105·27	5,852

[1] These specimens were not crushed, 100 tons being the maximum pressure which the Press was capable of giving.
[2] Just on the point of crushing.

TABLE XXXVI.

QUANTITIES used in making Brickwork Blocks, in Compo composed of Portland Cement and River Sand in equal proportions, each Block being a 3 feet cube = 1 cubic yard. February, 1865. Number of Bricks in each Block, 384.

MATERIALS.	No. 1 Block. Gault Bricks with Frogs. Average, 8·75×4·1 ×2·75=98·6562		No. 2 Block. Gault Bricks, Wire Cut, no Frogs. Average size, 9·08 ×4·14×2·75=105·08.		No. 3 Block. Sand Stocks. Average size, 9·08 ×4·21×2·70 =105·7573.	
	Bushels.	Cubic Feet.	Bushels.	Cubic Feet.	Bushels.	Cubic Feet.
Cement weighing 112 lbs. per bushel	3·615	4·6406	3·29	4·2187	3 29	4·2187
Sand	3·615	4·6406	3·29	4·2187	3·29	4·2187
Bricks	17·090	21·9236	17·98	23·0786	18·29	23·4780
Totals	24·320	31·2048	24·56	31·5160	24·87	31·9154

TABLE XXXVII.

SHOWING Two Series of Experiments as to the Quantities of Portland Cement, Sand, and Water used in making One Cubic Yard of Compo, or Cement Mortar.

P.C.		Sand.	FIRST SERIES.	Bushels.	SECOND SERIES.	Bushels.
1	to	1	Cement	12¼	Cement	13
			Sand	12¼	Sand	13
				24½		26
			56 Gallons of Water.		48 Gallons of Water.	
1	to	2	Cement	8¼	Cement	8½
			Sand	16½	Sand	17
				24¾		25½
			44 Gallons of Water.		36 Gallons of Water.	
1	to	3	Cement	6½	Cement	6¼
			Sand	19½	Sand	18¾
				26		25
			46 Gallons of Water.		28½ Gallons of Water.	
1	to	4	Cement	5¼	Cement	5
			Sand	21	Sand	20
				26¼		25
			47 Gallons of Water.		38 Gallons of Water.	
1	to	5	Cement	4¼	Cement	4⅛
			Sand	21¼	Sand	20⅝
				25½		24¾
			51 Gallons of Water.		34 Gallons of Water.	

TABLE XXXVIII.

EIGHTY Experiments with Neat Portland Cement immersed in Water immediately on Setting, intended to Illustrate the Increase of Strength from One to Fourteen Days. Weight, 104 lbs. per Bushel.

The Series for each Day consisted of Ten Samples out of a Quantity selected from various Bags.

Age of Specimens in Days.	Average Breaking Strain on 2·25 Square Inches.
	lbs.
1	133·
2	417·7
3	500·8
4	540·4
5	586·0
6	665·9
7	705·5
14	826·8

TABLE XXXIX.

SHOWING Tensile Strains of Cements of different Specific Gravities at different Periods. Sectional area, 2·25 square inches.

No. of Table.	Weight per Bushel.	1 Week.	1 Month or 4 Weeks.	1 Year.
	lbs.			
19	109	767·6	886·4	1099·0
16	112	558·5	784·5	1009·8
17	112	445·0	679·9	1075·7
18	123	817·0	935·8	1229·7

TABLE XL.

SOUTHERN OUTFALL WORKS, CROSSNESS.

SUMMARY of Portland Cement Tests, from 1862 to 1866, showing generally increase of Strength with increased Specific Gravity.

Number of Bushels.	Average Weight per Bushel.	Tensile Strain on area = 2·25 Square Inches.
	lbs.	lbs.
1,800	106	472·6
5,800	107	592·3
26,166	108	650·1
37,036	109	646·6
20,820	110	708·3
6,900	111	693·8
13,812	112	687·5
10,610	113	701·5
24,224	114	699·7
16,240	115	705·5
27,400	116	768·3
26,800	117	718·4
23,306	118	644·1
12,500	119	777·9
18,530	120	732·3
15,144	121	705·6
5,000	122	716·6
5,428	123	673·6
13,400	124	819·9
5,400	125	816·2
1,800	126	657·2
1,800	127	864·6
3,600	128	916·6
1,820	129	920·2
1,800	130	913·9
327,136	..	550·6

TABLE XLI.

SOUTHERN OUTFALL WORKS, CROSSNESS, JANUARY, 1866.

FOUR HUNDRED AND EIGHTY EXPERIMENTS with Neat Portland Cement, showing Strength after setting from One to Seven Days.

Days Immersed in Water.	Messrs. White & Co., Blackfriars.		Burham Company, Crossness.		Burham Company, Specimens.		Messrs. Francis, Nine Elms.		Burham Company, Woolwich.		Messrs. Weeks, Plumstead.		Burham Company, Crossness.	
	Weight 98 lbs.		Weight 104 lbs.		Weight 112 lbs.		Weight 115 lbs.		Weight 116 lbs.		Weight 118 lbs.		Weight 118 lbs.	
	Tensile Strain on 2·25 Sectional Area.	Tensile Strain per Square Inch.	Tensile Strain on 2·25 Sectional Area.	Tensile Strain per Square Inch.	Tensile Strain on 2 25 Sectional Area.	Tensile Strain per Square Inch.	Tensile Strain on 2·25 Sectional Area.	Tensile Strain per Square Inch.	Tensile Strain on 2·25 Sectional Area.	Tensile Strain per Square Inch.	Tensile Strain on 2·25 Sectional Area.	Tensile Strain per Square Inch.	Tensile Strain on 2·25 Sectional Area.	Tensile Strain per Square Inch.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1	195	87	116	52	202	90	170	76	125	56	171	76	134	60
2	295	131	279	124	391	174	450	200	395	176	486	216	417	185
3	347	154	356	158	541	240	594	264	428	190	607	270	501	223
4	418	186	505	224	590	262	824	366	499	222	708	315	540	240
5	462	205	471	209	768	341	811	360	575	256	777	345	586	260
6	481	214	519	231	..	..	791	352	599	266	681	303	666	296
7	475	211	575	256	740	329	947	421	614	273	650	289	705	313

TABLE XLII.

SOUTHERN OUTFALL WORKS, CROSSNESS.

EXPERIMENTS in Crushing Blocks of Granite, York, Portland, and Bramley Fall Stones; and neat Portland, Roman, Parian, Medina, and Keene's Cements.

Size of Blocks, 3 in. × 3 in. × 1½ in. Crushed by Hydraulic Press, January 8th, 1866.

1	2	3	4	5	6	7	8	9	10	11	12	
No. of Specimens.	Description of Blocks.	Age.			Area exposed to Compression.	Compression.			Pressure borne per Square Inch.		Tensile Strain per Square Inch.	Remarks.
		In Water.	Out of Water.	Total.		Minimum.	Maximum.	Average.	On Edge, Area 4·5.	Flat, Area 9·0.		
		Days.	Days.	Days.	Inches.	Tons.	Tons.	Tons.	lbs.	lbs.	lbs.	
5	Granite Stone	..	..	..	4·5	11·4	19·4	15·80	7,865	..	..	
5	ditto	..	..	..	9·0	25·4	47·4	38·12	..	9,488	..	
10	York Stone	..	..	..	4·5	9·3	17·6	12·81	6,376	..	..	
10	ditto	..	..	..	9·0	37·8	47·4	40·52	..	10,085	..	Two pieces of Portland stone cut to shape and size of the cement moulds = 1½ inch × 1½ inch = 2·25 square inches.
10	Portland Stone	..	..	..	4·5	3·1	8·7	5·79	2,882	..	..	
10	ditto	..	..	..	9·0	13·8	22·2	18·44	..	4,589	..	
2	ditto	..	..	..	..	..	..	..	..	..	296	
10	Bramley Fall Stone	..	..	..	4·5	3·6	6·2	4·89	2,434	..	..	
10	ditto	..	..	..	9·0	17·6	28·6	21·18	..	5,272	..	
10	Portland Cement	7	1,049	1,056	4·5	8·4	15·0	10·62	5,287	..	318	The tensile strain is taken on Specimens of the age shown in Columns 3 and 4. The Portland Cement was the same as used on the Southern Outfall Works, Crossness.
10	ditto	7	776	783	4·5	7·0	9·8	7·89	3,928	..	218	
10	ditto	7	619	626	4·5	10·1	18·0	13·51	6,725	..	413	
10	ditto	7	333	340	4·5	7·1	15·0	10·93	5,442	..	371	
10	ditto	7	364	371	4·5	7·6	9·7	8·72	4,341	..	334	
10	ditto	7	1,034	1,041	4·5	7·8	11·0	9·69	4,823	..	317	
10	ditto	7	754	761	4·5	7·4	11·0	9·13	4,546	..	331	
10	ditto	7	664	671	4·5	6·8	11·2	9·15	4,555	..	322	
10	ditto	7	1,042	1,049	9·0	16·8	29·6	24·74	..	6,158	274	
10	ditto	7	776	783	9·0	18·8	24·6	21·44	..	5,336	253	
10	ditto	7	623	630	9·0	22·3	32·1	27·40	..	6,820	389	
10	ditto	7	364	371	9·0	20·6	32·8	23·90	..	5,948	287	
10	ditto	7	754	761	9·0	16·4	34·8	22·38	..	5,570	328	
10	ditto	7	668	675	9·0	17·8	30·0	22·80	..	5,675	324	
10	ditto	7	438	445	9·0	21·0	26·0	22·78	..	5,670	325	

TABLE XLII.—Experiments in Crushing Blocks of Granite, York, Portland, and Bramley Fall Stones, &c.—*continued.*

1	2	3	4	5	6	7	8	9	10	11	12	
No. of Specimens.	DESCRIPTION OF BLOCKS.	Age.			Area exposed to Compression.	Compression.			Pressure borne per Square Inch.		Tensile Strain per Square Inch.	REMARKS.
		In Water.	Out of Water.	Total.		Minimum.	Maximum.	Average.	On Edge, Area 4·5.	Flat, Area 9·0.		
		Days.	Days.	Days.	Inches.	Tons.	Tons.	Tons.	lbs.	lbs.	lbs.	
5	Roman Cement .	7	667	674	4·5	3·7	4·8	4·26	2,121	..	88	
4	ditto .	14	653	667	4·5	3·9	5·0	4·45	2,215	..	81	
2	ditto .	21	653	674	4·5	5·0	6·0	5·50	2,738	..	83	
2	ditto .	31	643	674	4·5	3·9	4·5	4·20	2,091	..	113	
2	ditto .	93	581	674	4·5	4·0	5·7	4·85	2,414	..	147	
2	ditto .	183	490	673	4·5	5·8	7·5	6·65	3,310	..	207	
2	ditto .	274	399	673	4·5	7·0	8·9	7·95	3,958	..	208	
2	ditto .	365	307	672	4·5	8·1	8·6	8·35	4,157	..	296	
5	ditto .	7	667	674	9·0	8·7	12·0	10·38	..	2,584	92	
3	ditto .	14	660	674	9·0	8·4	15·4	11·23	..	2,795	73	
9	ditto .	21	653	674	9·0	8·2	13·6	10·88	..	2,708	84	
4	ditto .	31	642	673	9·0	8·5	11·2	9·30	..	2,315	114	
2	ditto .	93	580	673	9·0	10·8	11·4	11·10	..	2,764	145	
2	ditto .	183	490	673	9·0	16·0	21·6	18·80	..	4,679	202	
2	ditto .	275	398	673	9·0	19·2	20·8	20·00	..	4,978	218	
2	ditto .	365	308	673	9·0	16·0	18·6	17·30	..	4,306	296	
2	ditto .	7	678	685	9·0	8·0	8·8	8·40	..	2,091	179	
2	ditto .	14	670	684	9·0	6·4	7·4	6·90	..	1,717	71	
2	ditto .	21	663	684	9·0	9·4	9·5	9·45	..	2,352	187	
2	ditto .	31	653	684	9·0	12·8	14·8	13·80	..	3,435	192	
2	ditto .	91	594	685	9·0	9·0	12·6	10·80	..	2,688	159	
2	ditto .	183	501	684	9·0	13·6	15·2	14·40	..	3,584	179	
3	ditto .	273	411	684	9·0	13·0	13·4	13·26	..	3,300	118	
2	ditto .	365	319	684	9·0	21·6	25·2	23·40	..	5,824	134	
2	ditto .	7	678	685	4·5	3·0	3·7	3·35	1,668	..	180	

TABLE XLII.—Experiments in Crushing Blocks of Granite, York, Portland, and Bramley Fall Stones, &c.—*continued.*

1 No. of Specimens.	2 Description of Blocks.	3 Age. In Water.	4 Age. Out of Water.	5 Age. Total.	6 Area exposed to Compression.	7 Compression. Minimum.	8 Compression. Maximum.	9 Compression. Average.	10 Pressure borne per Square Inch. On Edge, Area 4·5.	11 Pressure borne per Square Inch. Flat, Area 9·0.	12 Tensile Strain per Square Inch.	Remarks.
		Days.	Days.	Days.	Inches.	Tons.	Tons.	Tons.	lbs.	lbs.	lbs.	
2	Roman Cement .	14	671	685	4·5	3·1	4·5	3·80	1,892	..	186	
2	ditto .	21	664	685	4·5	4·1	4·5	4·30	2,140	..	188	
2	ditto .	31	654	685	4·5	4·6	4·8	4·70	2,340	..	193	
4	ditto .	91	594	685	4·5	5·0	7·8	5·75	2,862	..	148	
2	ditto .	183	502	685	4·5	7·7	8·0	7·85	3,908	..	170	
3	ditto .	273	411	684	4·5	7·4	9·0	8·00	3,982	..	75	
6	ditto .	365	319	684	4·5	7·3	9·8	8·50	4,231	..	159	
10	Parian Cement .	61	*449	510	4·5	4·5	9·0	6·82	3,395	..	322	* Time made, but not put in Water.
10	ditto .	91	*419	510	9·0	16·0	18·6	17·12	..	4,261	379	
2	ditto .	7	486	493	4·5	4·4	6·0	5·2	2,588	..	263	
2	ditto .	14	479	493	4·5	3·0	4·4	3·7	1,842	..	261	
2	ditto .	21	470	491	4·5	3·1	4·1	3·6	1,792	..	249	
2	ditto .	30	461	491	4·5	4·2	5·6	4·9	2,439	..	245	
2	ditto .	61	430	491	4·5	2·5	3·9	3·20	1,592	..	213	
2	ditto .	92	399	491	4·5	4·0	4·4	4·20	2,091	..	240	
2	ditto .	7	486	493	9·0	15·4	16·8	16·1	..	4,007	254	
2	ditto .	14	479	493	9·0	15·0	18·4	16·7	..	4,156	265	
2	ditto .	21	470	491	9·0	13·2	14·2	13·7	..	3,410	236	
2	ditto .	30	461	491	9·0	12·8	16·0	14·4	..	3,584	231	
2	ditto .	61	430	491	9·0	11·6	13·6	12·60	..	3,136	231	
2	ditto .	92	399	491	9·0	14·6	18·6	16·60	..	4,131	236	
3	Medina Cement .	7	654	661	4·5	4·6	5·7	5·03	2,503	..	89	
3	ditto .	14	646	660	4·5	4·5	4·9	4·63	2,305	..	132	
3	ditto .	21	640	661	4·5	4·0	5·5	4·56	2,248	..	132	
3	ditto .	30	631	661	4·5	4·1	5·2	4·80	2,389	..	123	

TABLE XLII.—Experiments in Crushing Blocks of Granite, York, Portland, and Bramley Fall Stones, &c.—*continued.*

1	2	3	4	5	6	7	8	9	10	11	12	
No. of Specimens.	DESCRIPTION OF BLOCKS.	Age.			Area exposed to Compression.	Compression.			Pressure borne per Square Inch.		Tensile Strain per Square Inch.	REMARKS.
		In Water.	Out of Water.	Total.		Minimum.	Maximum.	Average.	On Edge, Area 4·5.	Flat Area 9·0.		
		Days.	Days.	Days.	Inches.	Tons.	Tons.	Tons.	lbs.	lbs.	lbs.	
2	Medina Cement .	91	570	661	4·5	5·5	6·4	5·95	2,962	..	193	
2	ditto .	183	478	661	4·5	7·4	7·5	7·45	3,708	..	185	
2	ditto .	273	388	661	4·5	7·1	8·1	7·60	3,783	..	213	
2	ditto .	365	296	661	4·5	7·0	7·4	7·20	3,584	..	204	
2	ditto .	7	653	660	9·0	10·0	10·2	10·10	..	2,514	97	
2	ditto .	14	646	660	9·0	9·1	10·4	9·75	..	2,427	121	
2	ditto .	21	638	659	9·0	10·4	10·6	10·50	..	2,613	127	
2	ditto .	30	630	660	9·0	9·5	10·8	10·15	..	2,526	129	
5	ditto .	92	568	660	9·0	13·2	14·6	14·24	..	3,544	201	
2	ditto .	183	477	660	9·0	20·0	22·8	21·40	..	5,326	190	
2	ditto .	273	387	660	9·0	16·8	17·6	17·20	..	4,281	199	
3	ditto .	365	295	660	9·0	16·2	22·4	19·86	..	4,943	207	
5	Keene's Cement .	7	516	523	9·0	12·0	14·4	13·36	..	3,325	247	
5	ditto .	14	509	523	9·0	9·7	14·4	11·42	..	2,842	218	
5	ditto .	21	502	523	9·0	9·8	17·0	14·00	..	3,484	222	
5	ditto .	30	493	523	9·0	11·8	15·6	14·12	..	3,514	216	
5	ditto .	60	463	523	9·0	11·6	14·6	12·84	..	3,195	202	
5	ditto .	92	431	523	9·0	11·0	17·0	14·68	..	3,956	224	

Table XLIII.

SOUTHERN OUTFALL WORKS, CROSSNESS.

Experiments with Blocks of various Substances, Crushed January, 1866.

Description.	Date when made.	Dimensions.	Cubical Contents.	Superficial area exposed to Press.	Crushing Power.	Crushing Power per Square Inch.	Weight of Specimen.	Remarks.
		Inches.	Inches.	Inches.	Tons.	lbs.	lbs.	
1 Portland Cement & 6 Thames Ballast .	March, 1865.	12 ×12 ×12	1,728	144	60·0	933	136	The crushing power is taken on first symptoms of failure.
1 ditto ditto .		12 ×12 ×12	1,728	144	52·4	815		
1 Portland Cement to 8 Thames Ballast[1] .		12 ×12 ×12	1,728	144	70·6	1,098		
1 ditto to 6 ditto .		12 ×12 × 6	864	144	40·4	628		
1 ditto ditto .		12 ×12 × 3	432	144	17·0	264		
1 ditto ditto .		12 ×12 ×12	1,728	144	63·0	980	..	Kept in Water.
1 ditto to 8 Thames Ballast .		12 ×12 ×12	1,728	144	83·2	1,294	..	
1 Blue Lias Lime & 6 Thames Ballast . .		12 ×12 ×12	1,728	144	6·0	93	133	
1 ditto & 6 Bramley Fall Chippings		12 × 7½ × 6	540	90	5·0	124	..	
1 ditto & 6 ditto		12 ×12 ×12	1,728	144	20·4	317	..	
1 Portland Cement and Port Nant Granite Chippings.		12 ×12 ×12	1,728	144	58·6	911	..	
1 Block of Brickwork, 1 Cement to 1 Sand	Jan., 1865.	13½ ×12 × 9	1,458	162	21·6	299		
1 ditto ditto		12 ×18 × 9	1,944	216	20·8	216		
1 ditto ditto		13½ × 9 × 9	1,094	122	15·2	295		
1 ditto ditto		18 × 9 × 9	1,458	162	16·0	221		
1 Neat Portland Cement	Dec. 22, 1865.	12 ×12 ×12½	1,800	144	*	..	139	* 100 tons would not fracture this Specimen.
1 Block ½ Portland Cement ½ Sand . .		12 ×12 ×10⅜	1,494	144	95·0	1,478	115	
1 ditto ⅓ ditto ⅔ ditto . . .		12 ×12 ×10¼	1,476	144	75·0	1,167	112	
1 ditto ¼ ditto ¾ ditto . . .		12 ×12 ×11	1,584	144	47·0	731	117	
1 ditto ⅕ ditto ⅘ ditto . . .		12 ×12 ×10⅛	1,458	144	26·0	404	107	
1 ditto ⅙ ditto ⅚ ditto . . .		12 ×12 ×10⅛	1,458	144	23·0	358	107	

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[1] The weight of one cubic yard of Portland cement concrete (1 to 8), wet, as put into the work, was 30½ cwt. = 3,416 lbs. = 126 lb, p cu ft

CLAUSE AS IN EARLIER SPECIFICATIONS.

21. The whole of the cement to be used in these works and referred to in this specification, is to be Portland cement of the very best quality, ground extremely fine, weighing not less than 110 lbs. to the striked bushel, and capable of maintaining a breaking weight of 400 lbs., seven days after being made in an iron mould, of the form and dimensions shown on drawing No. 1, and immersed six of these days in water.

CLAUSE AS FIRST AMENDED.

27. The whole of the cement shall be Portland cement of the very best quality, ground extremely fine, weighing not less than 110 lbs. to the striked bushel, and capable of maintaining a breaking weight of 500 lbs. seven days after being made in an iron mould, of the form and dimensions shown on Drawing No. 1, and immersed in water during the interval of seven days. The Contractor shall at all times keep in store upon the works a supply of cement equal to at least fourteen days' requirements; and with each delivery of cement shall send to the Clerk of Works a memorandum of the number of bushels sent in, and the name of the manufacturer.

CLAUSE AS LAST AMENDED.

25. The whole of the cement shall be Portland cement of the very best quality, ground extremely fine, weighing not less than 112 lbs. to the striked bushel, and capable of maintaining a breaking weight of 250 lbs. per square inch seven days after being made in a brass mould, and immersed in water during the interval of seven days. The Contractor shall at all times keep in store upon the works a supply of cement equal to at least fourteen days' requirements; and with each delivery of cement shall send to the Clerk of Works a memorandum of the number of bushels sent in, and the name of the manufacturer.

METROPOLITAN MAIN DRAINAGE.

Register of Portland Cement.

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Delivered.	Quantity in Bushels.	Weight per Bushel.	When Moulded.	When Tested.	Days in Moulds.	Broke at lbs.	No. of Test.	Remarks.
1.	2.	3.	4.	5.	6.	7.	8.	

[Mr. G. W. Hemans

Mr. G. W. **Hemans** thought the Paper just read formed the best record of experiments on cement, that had hitherto been brought forward. He hoped the discussion would lead to the consideration of what seemed to him to be the most interesting application of cement, viz., the practicability of using it for forming piers or walls in water, where currents prevailed, so as to get rid of the cumbrous and expensive plan of constructing coffer-dams. In 1862, a Paper was read before the Institution, on deep-sea constructions of this nature,[1] at which time the amount of knowledge with regard to cements and bétons was less than it was now. Some facts in the Paper were new to him. One was, that Portland cement appeared to set better in salt water than in fresh water; that was a valuable discovery. Another new point, and in some respects rather alarming, was that this cement was not applicable where there were currents of water. But a considerable extent of sea wall had been, he believed, constructed at Brighton and other places, where Portland cement was largely used, without detriment, in situations exposed to the action of tides and currents. If no further experiments removed the difficulty with respect to the use of Portland cement in moving water, its application to béton piers would be very limited. He thought that in England Engineers were too timid in the application of concrete. Works were often required which would not bear the expense of building coffer-dams; it was, therefore, time this question should be better understood. In France, Engineers who wanted to put a pier in deep water, simply constructed a wooden box in the water, which they filled with béton, of better quality than that which had hitherto been used in this country; and when the work was raised to the level of the surface of the water, they built the masonry upon it with great success, and this plan he was about to carry out, in conjunction with Mr. Barton (M. Inst. C.E.), in Carlingford Bay, in deep water, where it was impossible, with the means at their disposal, to build an ordinary coffer-dam; the depth at low water being 19 feet, and the rise of tide 16 feet more. A wooden box was, in fact, the only covering that could be afforded. The concrete would be deposited in the salt water for a depth of 19 feet, and on that, the masonry would be built. The concrete system of construction was relied upon with so much confidence, that it was proposed to remove the wood entirely from the back of the structure, leaving it only in front, and as it was evident the front casing could only be temporary, the result would be, that the whole weight of the superstructure, the total height being 46 feet, would rest upon the concrete alone, which would eventually be exposed to the action of the sea. Until this Paper was read, he had resolved to construct that foundation with béton, formed of Portland cement; but if the deductions of the Author were true—and it was right to take them as such, from the extreme care with which the experiments were conducted—it would appear that, in this instance, with a rise of tide of 16 feet, it would be inapplicable. He hoped other members would be able to throw more light on the use of Portland cement in such positions, in order that they might judge whether it was prudent to rely upon it, instead of the ordinary hydraulic limes, for the composition of that description of béton. The cost of the wall he had alluded to, on the plan he had proposed, would be about £50 per running foot, while the construction of a coffer-dam would enhance the cost by about £10 to £15 per foot, and the removal of the dam would, under the circumstances stated, endanger the work, and where the pecuniary means at command were limited, that risk could not be run.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., p. 417.

Mr. ABERNETHY said, the question of the use of Portland cement for the foundations of marine works had been one of great interest to him for many years past, and he had gathered from the Paper one or two facts which he was not previously acquainted with. There was one fact, however, with which all were well acquainted, viz., that the sand used in cement must be sharp and clean; but the information which was most satisfactory to him was, that Portland cement set better in salt water than in fresh.

With regard to the doubts as to employing Portland cement in situations exposed to currents, it occurred to him that if the wooden boxes were used, that difficulty would be removed.

Mr. HEMANS said, the box would be used only up to low-water mark.

Mr. ABERNETHY added, under those circumstances, the concrete in the box would only be exposed on the surface. He thought Mr. Hemans might safely undertake the work in the way he proposed, inasmuch as the concrete would be, for a considerable time, protected from the action of the current by the facing of the box.

Mr. DRUCE said, a large quantity of Portland cement had been used in the pier works at Dover, all of which had been carefully tested, and he could corroborate the opinion, by his own experience, that no detriment to the cement was occasioned by the use of it in salt water. Where currents prevailed, he had found that cement in liquid concrete, from its slow-setting property, was liable to be washed away; but after it was once set, it was not affected by them. The difficulty with Portland cement was to obtain it of thoroughly good quality, the demand for it, at the present time being beyond the means of supply. With reference to the mode of testing, he had adopted the steelyard system, for the last ten years, but he did not think it sufficient. He had met with many instances in which cement, after having stood the ordeal of that machine, and shown high results, had afterwards entirely failed from causes for which the cement-maker was chiefly to blame. The surest way to guard against the effects of inferior or "blowing" cement, was to have a sufficient stock on hand to enable it to be thoroughly air-slaked, before it was used. Provided it was kept from damp it could not have too much air. His practice at Dover was to expose it to the air, for at least one month, which reduced the imperfectly burnt portions to an inert and harmless condition; and since that had been done, faulty cement in the work had become very rare.

A point to be considered was the size of the test-blocks. He believed more reliable results were obtained from blocks having an area of about six inches, than from smaller ones. A sure criterion of quality was the weight per bushel, and that depended a great deal upon the burning. As an instance of the little effect produced by currents upon Portland cement, he would state, that in the construction of a small pier on the Sussex coast, Portland cement concrete blocks had been used with satisfactory results, even where exposed to the action of the tide and the constant abrasion of shingle; and it had stood for some years the wear and tear of them. He regarded this as a most valuable cement for hydraulic work, and for very many purposes it was far superior to any other; but the continuous and careful testing required was a disadvantage connected with its use.

Mr. ROBERT RAWLINSON, C.B., remarked, that some years ago, he had acquired considerable experience in the use of hydraulic mortars and cements. If he might be permitted to do so, he would inquire how the Author specified for the mixing of the Portland cement—whether it was mixed on mortar-boards with a shovel, or ground in a pan, or in what way it was mixed; and, whether mortar, which had been mixed over night, and stood all night, was allowed to be re-tempered and used in the work. There was one application of Portland cement not generally known, viz., its use, when of good quality, under water, by the aid of a diver. He had used it to make a joint between iron and iron, under a 90-feet head of water, with perfect success, to keep out a quicksand. No other means had enabled him to master that quicksand. He had occasion to sink a well, where there was a quicksand at the depth of 90 feet, overlaid by a thick bed of marl, and underlaid by new red sandstone rock. A first well was sunk in the ordinary manner, by miners of the district, and, being an utter failure after two years' work, was abandoned. The second well was sunk within thirty feet of the same site, by 7-feet cylinders, which were sunk without pumping, and lowered by working inside, till they rested on the new red sandstone rock; but the dip of the rock was at such an angle that the 7-feet cylinder could not be made to bed into its surface. He then worked with drills in the sandstone rock, by placing a second cylinder inside the first, with a cast-iron diaphragm bottom, having a 2-feet hole in the centre for the passage of the boring tool; but the difficulty was to make the joint between the two cylinders tight. The ordinary iron cement, of iron borings and sal-ammoniac, would not set, but washed out. He then sent down pure, stiffly-made Portland cement in buckets; this was put in place by divers and set perfectly, where it had remained for three or four years, though exposed to a severe strain, by the constant pumping.[1] He should be glad of further information upon the cost of Portland cement. All the mortar used at the Liverpool Docks —and there could be no better for hydraulic purposes—was made with sea sand, and mixed with salt water. The limestone was from Halkin, in North Wales, was burned at the works, drawn warm from the kiln, slaked on the floor, mixed with 1 part sea sand, ¼ part furnace ashes, ground in a revolving pan 20 minutes, and cost, net on the floor of the mill, from 9*s.* to 10*s.* per cubic yard. He thought Portland cement would be, at least, three times that cost. At the Liverpool Docks four cubic yards of brickwork contained one cubic yard of mortar, or in the proportion of 1 to 4. In rubble work the proportion was 3 to 1. In other words, three cubic yards of rubble contained one cubic yard of mortar. Mr. Hartley abandoned the use of ashlar for facing sea and dock walls, and relied upon granite rubble. The red sandstone ashlar cost about 24*s.* to 30*s.* per cubic yard, and the granite facing rubble, only from 12*s.* to 15*s.* per cubic yard; red sandstone rubble backing cost about 9*s.* per cubic yard. One of the great uses of Portland cement, or mortar like that at the Liverpool Docks, would be, to enable engineers to accomplish great works of this class—river walls and dock works—at much less cost than by using the more expensive granite ashlar veneering. Last autumn he visited the works at Cherbourg, than which, as specimens of ashlar masonry, perhaps finer could not be seen. The inner harbour, graving docks, and the several structures on the great breakwater there were all, however, faced with granite ashlar. To show the misuse of this granite ashlar veneering, he might mention, that probably from a ship coming in contact with it, a considerable length of the said granite ashlar face work, had fallen into the entrance of the harbour, leaving the rubble backing standing, as sound as the day on which it was put up. The casemate forts on the breakwater were splendid specimens of granite ashlar, but they were rent and split in all directions by the giving way of the foundations, and by the impossibility of the mortar, in their beds and joints, holding such work together. If that work had been executed on the plan adopted by Mr. Hartley, for the last twenty years, viz., rubble to the face, it would have saved the French Government one-third of the entire expense of those works, and the masonry would have been of much greater strength. Forts, instead of being faced with ashlar, would be stronger and more fit for their purpose, if built with good solid rubble put together with hydraulic mortar, or with Portland cement, of this, or of an analogous character. Ashlar would split, and break away in lumps and masses, under the pounding of heavy artillery. Rubble work would not split in like manner, but would rather indent and crush; only the immediate part struck being affected, and small portions being detached.[1]

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[1] To close the joint round the bore pipe passed through the diaphragm, Portland cement concrete was used, sent down also in 90-feet of water, spread out and placed by a diver.

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[1] The following details relative to Halkin Mountain limestone were subsequently supplied by Mr. Rawlinson. This limestone is obtained from quarries situate near Holywell, Flintshire. Limestone from these quarries has been obtained for the great hydraulic works at the Liverpool Docks, for the last thirty years.

The following analysis by Dr. S. Muspratt, of Liverpool, was made in 1862 :—
This hydraulic limestone affords—

Substances soluble in acids	74·726 per cent.
Substances insoluble in acids	25·274 „

These two classes afford the following approximate components—

		Centesimally.
Substances soluble in acids.	Carbonate of lime	71·546
	Carbonate of magnesia	1·348
	Proto-carbonate of iron Sulphide of iron	1·040
	Alkalies.	0·792
Substances insoluble in acids.	Silicic acid	20·068
	Alumina	3·521
	Sesquioxide of iron, &c.	1·192
	Water and carbonaceous matter . .	0·493
		100·000

The sample of limestone, of which the preceding is a carefully-performed analysis, is of the blue lias variety.

The components, which induce cementation of the mortar under water, exist in this sample of lime, to an extent of about one-fourth of its weight. The carbonate of lime and other matters soluble in hydrochloric, or nitric acids are in proportion as one to three. The best cement or mortar is obtained from limestones which contain carbonate of lime, magnesia, and clay, naturally commingled in this ratio, of three parts of the former, to one of the latter. The quantity of silicic acid and silica which exists in Halkin Mountain limestone, as per sample analyzed, being evenly distributed through its entire mass, is rendered, by calcination of the stone, most favourable to the production of an insoluble crystallized silicate of lime, when made into mortar.

This limestone burns to a yellowish-white colour, producing lime of average whiteness.

At the Liverpool Docks, the lime kilns and mortar mills are situate together. The fresh-burned lime is drawn from the kiln, slaked, mixed with sea sand and furnace ashes, put in the mortar pan, and ground for immediate use.

[Best

Mr. G. F. White, as a manufacturer of Portland cement, desired to express his high appreciation of the Paper, the details of which were, for the most part, in accord with his own experience. He thought the Meeting would agree with him, that greater intelligence and honesty of purpose could hardly have been brought to the investigation of the subject than had been evinced by the Author, who, whilst consulting, as was his duty, the interest of the public, yet, at the same time, dealt in the fairest manner with those manufacturers who had been brought into contact with him.

In the few remarks he had to make, he should direct attention particularly to the question of the "specific weight" of the cement which the Engineers of the Board of Works had exacted from the manufacturers. It might be remembered, that in the year 1852, he had presented a Paper to the Institution, containing "Observations on Artificial Hydraulic, or Portland Cement,"[1] the object of which was, to explain the composition of that material, and to place on record the results of the experiments which had, up to that period, been made on the cement, chiefly by the Engineers of the French Government. For the first few years after its introduction, Portland cement had been supposed, even by Engineers, to be, in part at least, composed of Portland stone. In the Paper referred to he had explained that it was an artificial compound of chalk and clay, the peculiar nature and proportions of which had been quite correctly re-stated in the Paper just read. In introducing a cement of this character it was very necessary to adopt some general standard of excellence, and the Engineers of the Ponts et Chaussées, to whom this cement had been introduced about the year 1850, were not slow in bringing the analyzing powers of the French mind to bear on the subject. They had proposed, and applied numerous tests, which had not been

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Best mortar :—	Lime,	by measure,	1	part.
	Sand	,,	1	,,
	Ashes	,,	¼	,,
Common mortar :—	Lime	,,	1	,,
	Sand	,,	2	,,
	Ashes	,,	¼	,,

It is ground in pans, which revolve beneath heavy cast-iron rollers, so that the process crushes by partial sliding as well as by grinding.

This mortar on the floor, when made, costs from 8*s.* to 10*s.* per cubic yard.

Random rubble requires about 1 cubic yard of mortar, to 3 cubic yards of rubble masonry. Brickwork requires about 1 cubic yard of mortar, to 4 cubic yards of brickwork. Grout is made by diluting the best mortar with water until it will pour evenly over the work. Both rubble masonry and brickwork, when used in dock, sea, or river walls, are regularly grouted as the work proceeds, so as to wet the entire mass, and every stone and every brick is bedded, jointed, and covered by grout and mortar, so as to constitute one solid mass.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xi., p. 478.

materially varied to the present day, and which, for the sake of comparison with the Board of Works' tests, might be stated as follows:—

Specific weight . . 1,200 kilogrammes per mètre, cube, or 103 lbs. per imperial bushel.

Tensile strain, tried on bricks with the same sectional area employed by the Board of Works, viz., 2·25 square inches.

Neat Cement . .	2 days	64 kilogrammes, or	140 lbs. per brick.
	5 ,,	128 ,,	280 ,,
	30 ,,	240 ,,	530 ,,
Cement 1 part . .	5 ,,	64 ,,	140 ,,
Sand 2 parts . .	30 ,,	128 ,,	280 ,,

The Engineers of the Board of Works were the first public officials in this country, who had instituted analogous tests, though Mr. Rendel, in the year 1852, and Mr. Druce, at a subsequent period, had carefully investigated the subject, in connection with the works at Holyhead and at Dover. The Board of Works' tests were of a threefold character: 1st. The cement must be of a given specific weight; 2nd. When gauged neat, it must have a certain resistance to tensile strain; 3rd. It must bear immersion in water, without sign of cracking. The tensile strain, at first fixed at 400 lbs., had been raised to 500·lbs., and the specific weight, fixed originally at 110 lbs., had been raised to 112 lbs. per bushel. It was to this test of 112 lbs. per bushel, which indicated a very heavily burnt cement, that he desired to direct some attention, as pressing severely on the manufacturers, without, as he believed, conferring any corresponding benefit on the Engineer. The way in which it affected the manufacturers was as follows:—In the first place, the less the concentration given to the cement by burning, the greater was the volume of cement that could be obtained from a given quantity of raw material. In other words, if a certain quantity of chalk and clay, calcined to the specific gravity of 104 lbs. per bushel, produced 21½ bushels of cement to the ton, the same quantity of raw material, burnt to weigh 112 lbs. per bushel, would produce only 20 bushels to the ton, and thus occasion the manufacturer a loss, in volume, of 7½ per cent. Secondly, cement of so high a specific gravity as 112 lbs. involved a much larger consumption of the fuel employed in burning it, an item which, under the most favourable circumstances, counted for nearly one-third of the prime cost of the cement. Thirdly, the destruction of kilns, and of the machinery employed in grinding the cement, was enormously increased by the intensity of the heat required to produce it, and by the hardness of the material to be ground. Fourthly, the quantity of this highly-calcined and heavy cement, that could be produced in any one kiln, bore only a certain proportion to a residue, which was not sufficiently burnt to produce cement weighing 112 lbs., but which could be employed advantageously in the manufacture of cement that was intended to set more quickly, and to weigh only 104 lbs. per bushel. And he might add—what was really, to the makers, the most important consideration of all—that very little, if any, increase of price was given for this heavy cement, over that which was so much less costly in the manufacture.

He would now, however, look at the question as it affected Engineers, and, first, this heavily burnt cement was a dangerous cement to use. It was well known to manufacturers, that to be able to push the calcination far enough to produce a cement of a uniform gravity of 112 lbs., it was needful to combine more lime with the clay than was required for lighter burnt cement; and that, in so doing, there was the risk that a perfect amalgamation of the lime and clay would not be effected; but some of the lime, being left in a free state, would be liable to be slaked by water, or even by the moisture of the atmosphere, and produce, sooner or later, the fatal disintegrations, which all Engineers had witnessed.

The next consideration was the slowness of the setting of this heavily burnt cement. The Author had stated, that it would not set in running water, and that, therefore, he had used means to prevent any water passing over the cement in the sewers during their construction. Now, Portland cement of English manufacture, had been successfully employed for concrete *en masse*, in constructing the under-water foundation for a lighthouse, on a coral reef in the Red Sea.[1] It was quite intelligible that, though the cement of 112 lbs. would set too slowly for this purpose, a lighter burnt cement would effect the desired object. To lose sight of this, and to insist that all cement, whatever its destined use, should be thus concentrated in burning, would be simply to deprive it of one of its most valuable properties—that of setting rapidly under water.

Another inconvenience, to which this heavily burnt cement exposed the Engineer, was the almost certainty that it would not be properly ground. Theoretically, the cement should be an impalpable powder, and every grain of sand a matrix, round which the cement should form a film, or coating; but this could scarcely be the case with a material, which it was so difficult to reduce to powder, as the heavy cement in question. On the contrary, if carefully scrutinized, by passing it through a sieve, or by washing it, a considerable residue of particles resembling sand would be found, comparatively inert in their character, with very feeble setting properties, and of a nature to diminish the amount of real sand which the cement would otherwise carry. He might also add, that the coarsest ground cement being found to weigh the heaviest, the exaction of a very heavy specific weight, unaccompanied by any other restriction, offered an inducement to imperfect pulverization.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiii., p. 1.

A fourth objection was the loss of volume, which would be sustained by the Engineer, equally with the manufacturer, if he were to become the buyer of cement by the ton, instead of having it furnished through the contractor. The Engineers of France, who almost always bought the cement for the government works under their charge, were careful to regulate this question, by procuring a cement of sufficient density to pass their tests, while stipulating that it should not exceed that weight, so as to produce a needless loss in volume.

In support of these views, he had compiled the following table (see next page), showing the requirements of the Board of Works and of the French Engineers, side by side, and the results of the tests which had been applied to the cement delivered to both of those services during the last five years or six years.

The French tests were made at two days, at five days, and at thirty days, on cement of 103 lbs. or 104 lbs. specific gravity; and it would be observed, that the cement supplied to meet these demands had been from 50 per cent. to 100 per cent. in excess of the requirement.

The Board of Works tests had been made at seven days, the requirements being—specific gravity 112 lbs., tensile strain 500 lbs., and the general average of the whole of the cement supplied for the works of the Metropolitan Main Drainage on the south side of the river Thames had been stated to be — specific gravity 114 lbs., tensile strain 606 lbs., or 270 lbs. per square inch. In one of the Tables (XXXVII.), however, the average strength of cement of 112 lbs. weight per bushel had been shown to be, at seven days, only 501 lbs., or 222 lbs. per square inch—which was on a par with the requirement and no more; while cement weighing but 104 lbs. had acquired, at seven days, a strength of 560 lbs., or 250 lbs. per square inch, being 12 per cent. in excess of the strength exacted by the Engineers of the Metropolitan Board of Works. When mixed with sand, the difference between the two cements was still more marked, for while, at seven days, the cement of 112 lbs. resisted only 90 lbs. per brick, or 40 lbs per square inch, the cement of 104 lbs. resisted, at five days, a strain of 196 lbs., or 87 lbs. on the square inch, being 40 per cent. in excess of the strength demanded by the French tests, and more than double that of the heavily-burnt cement. The comparisons were also in favour of the lighter cement at the age of thirty days, both neat, and with sand.

The only conclusion he could draw from these results was, that the test of specific weight was too variable to be relied on, if unac-

Results of Comparative Experiments on Portland Cement. Sectional Area of Briquette—2·25 square inches.

Neat Cement.	Requirements.				Results.				
	Board of Works. 112 lbs. per Bushel.		French Engineers'. 103 lbs. per Bushel.		Tests as recorded by Mr. Grant. 114 lbs. per Bushel.		White Brothers' Results of Daily Tests from 1860 to 1865. 104 lbs. per Bushel.		
Age when Tested.	Per Briquette.	Per Square Inch.	Per Briquette.	Per Square Inch.	Per Briquette.	Per Sq. Inch.	Per Briquette.	Per Square Inch.	Percentage above required strength.
2 Days . .	..	..	140	62	..	..	298	132	112 above French.
5 „ . .	..	..	280	124	..	..	437	192	55 „ „
7 „ . .	500	222	..	..	606	269	560	250	12 above Board of Works.
30 „ . .	..	..	530	236	Tables 16 and 17. 112 lbs. per Bushel. 708	314	775	344	47·5 above French.
CEMENT 1 PART—SAND 2 PARTS.									
5 Days . .	..	..	140	62	112 lbs. per Bushel. Table 16. ..	..	196	87	40 above French.
7 „ . .	..	..	..	..	90	40	..	..	
28 „ . .	..	..	..	..	180	80	288	128	

companied with other conditions; that the heavily-burnt cement would, very commonly, be coarsely ground, and that it would, in consequence, carry less sand, or, if gauged with two or three parts of sand (the usual proportion), it would be a long time in indurating. As a rule, only one part of sand to one of cement had been used in the sewers, which would, doubtless, make a strong, though it must be confessed a rather costly, mortar. Perfect pulverization was a more essential condition than great specific weight, and a lighter cement, more finely ground, would have carried two parts of sand, and made as good a mortar, at less cost.

The question here involved, however, was not so much one of high quality, or low quality, as of the adaptation of different classes of material to various sorts of work. Different works demanded, without doubt, different qualities of cement. Where a long time could be given for induration, a slow-setting cement might be advantageously used; but for tide-work and water-work generally, as well as for the purposes of ordinary building, medium burning, fine grinding, and rapid induration, were preferable to the slow induration, and the coarse grinding, which were the practical concomitants of the heavily-burnt cement.

Mr. Carleton Baynes said, that he had made experiments on cement weighing 114 lbs. to the bushel, which was moulded, and the bricks then immersed in water for periods varying from one day to seven days, one being broken each day. After one day in water, the cement broke at 275 lbs.; after two days, at 265 lbs., owing to a fracture in the mould; after three days, at 520 lbs.; after four days, at 580 lbs.; after five days, at 570 lbs.; after six days, at 765 lbs.; and after seven days, at 890 lbs. Another set of moulds, from a similar parcel, broke on the second day at from 254 lbs. to 378 lbs.

The test was excellent, and specially suited to the work in question; but he would suggest that there should be some limit, for, to judge from the tables, the cement of 123 lbs. to the bushel would be very superior to that of 112 lbs. to the bushel. He considered, that the cement of 112 lbs., *cœteris paribus*, would be a better cement than that of 123 lbs., on account of the slowness of setting of the latter. It was, indeed, quite a different cement to work, from that of 112 lbs., and that, in its turn, was quite different from a cement of 104 lbs. The hard-burnt cement was not generally useful; the builder and plasterer would be much disappointed if it were sent to them, and, in tide-work, a slow-setting cement was not desirable. In an article which was sold by the bushel, bulk was a thing to be desired, and if equal efficiency was attainable with a less specific weight, the lighter cement was preferable.

The conditions demanded for general purposes were to cover the greatest extent of surface, to be of uniform colour and setting power, and not to crack, or peel off from the brickwork; the breaking test would be of little service in obtaining these conditions.

There was probably no manufactured article which depended so much for its excellence on the manipulation it received as cement. Thousands of tons of good cement were spoilt by being improperly gauged, or by being gauged a second time after having partially set, and oftentimes first-rate cement was condemned, because a mason had not been accustomed to its particular way of setting. On great works, where large stores of cement must necessarily be kept, it was desirable that, instead of being stowed in bags, as was generally the custom, it should be shot in a large shed, and occasionally turned over. It would be as much to the interest of the Engineer as to that of the contractor, because the cement would be greatly improved by it. The cement was sometimes taken from the manufacturer quite hot and stored in bags, tons and tons over each other, and it had no chance of cooling; but was almost certain to 'blow' in the work.

In reply to an inquiry, Mr. Baynes said, in objecting to a heavy cement as being slow setting, he referred particularly to that weighing 123 lbs. per bushel. He was led to desire a limit to the specific weight required in cement, because it might be supposed, if cement was burnt to 130 lbs., it would be better than that which was burnt to only 123 lbs. When this heavy cement was gauged, it would not set enough to be taken out of the mould for a long time; it had then to be coaxed into the water, and, after all, three moulds or four moulds would often run together in the water, and the moulds would not keep their edges, though they stood this enormous breaking test. If, however, it had been tide-work, it could not have been humoured in that way. It was frequently requisite to let the cement set for hours, after being taken out of the mould, before putting it into the water; and of those briquettes, many would have to be trimmed to go into the machine, so as to be tested and broken.

Mr. C. L. **Francis** thought there was yet much to learn from the analysis of the materials of which cement was composed, as well as in its uses and application. Cements of so great weight were costly and inconvenient to the manufacturer, and should be costly to the consumer. It was stated in the Paper that, bricks of neat Portland cement, after being made three months, six months, and nine months, withstood a crushing force of 65 tons, 92 tons, and 102 tons respectively, or were equal in strength to the best quality of Staffordshire blue bricks; and that bricks of the same cement mixed with four parts and five parts of sand, bore a pressure equal to the best picked stock bricks; while Portland stone of similar size bore, on its bed, a crushing weight of 47 tons, and against its bed somewhat less, and Bramley Fall stone sustained on its bed 93⅓ tons, and against its bed 54⅔ tons. Portland stone crushed easier than the lowest experiment with Portland cement. Where, then, was the practical use of having a cement stronger than the material which had to be joined together? If the stone decayed, what were the joints good for? He believed that cement of from 100 lbs. to 103 lbs. would last as long as any materials it could unite. With respect to the preliminary experiments, made with samples of Portland cement, of the average weight of 108·6 lbs. per bushel, it appeared that they sustained breaking, or tensile strains varying from 75 lbs. to 719 lbs. upon 2¼ square inches. Manufacturers produced cements of different weights and quality. In his own case, he generally manufactured cement weighing from 100 lbs. to 104 lbs. per bushel, and he thought to make it from 112 lbs. to 114 lbs. was quite a superfluous strength; and when such a difference as between 75 lbs. and 719 lbs. was shown, it ought to be known, whether the same description of cement was used, otherwise the experiment could not be regarded as a fair one. But the great question to be considered was, the advantage to be gained by having a cement stronger than the material it had to unite, and therefore unnecessarily costly.

Mr. J. W. **Bazalgette** felt it to be his duty to bear testimony to the great care which was taken by the Author in conducting these experiments. The facts laid before the Institution were nothing but the naked truth. He believed, that great good had been done by the tests; that the manufacture of cement had been improved thereby; and that Portland cement was destined to be used, to a much larger extent than it had been hitherto in engineering works. In many cases, Portland cement would bear admixture with sand, so as to enable it to compete in price with common mortar, and secure greater strength in the work at the same expenditure. The time would probably arrive, when all Engineers would test their own cement, and would obtain the best that was to be had; and those tests would give more confidence than the character of any firm, although much value should always be attached to the character of the manufacturer, and would yet improve the manufacture of cement. He regarded the test of weight as one of considerable importance. It had been ingeniously suggested, that the weight of 112 lbs. per bushel was adopted because it was one cwt., and twenty sacks of cement made a ton; but, as would be seen from the Paper, 110 lbs. to the striked bushel was first adopted, not one cwt. That weight was selected after careful experiments, and if, after obtaining these results, it was found by further experience and experiments, that it might be increased with advantage, it was a proof that an excessive weight had not been chosen in the first instance. That the heavier cements bore the greatest strain, was clearly found to be the case. An examination of the tables would show, that as a rule, the cement burned to weigh 112 lbs. and upwards would bear a considerably greater strain than cement of less weight; that it was in fact the best, and there was no exception to that rule. A manufacturer's experiments upon his own cement could hardly be accepted, in contrast with experiments made by impartial and independent persons upon the cements of various other manufacturers, taking the cement from the bulk—good and bad together—and gauged perhaps not under the same advantages as would probably be secured by the manufacturer testing for himself. Then it had been argued, that if the cement was stronger than the materials which it had to unite, it was not surprising that the manufacturer should be unwilling to raise the standard of quality. But he had yet to learn that any cement had been obtained which was "too good." When that pitch was arrived at, it could readily be diluted with a larger amount of sand, and its cost and its strength could be reduced, at pleasure. It was the Engineers' duty to raise the standard of quality, and when it had fairly been determined what was the best material, it would always command its price in the market, and that would determine the question, which was the most marketable article to produce.

With reference to the setting of Portland cement in running water, he did not know that there was greater objection to using Portland cement in running water than any other kind of cement. If care were not taken, all cements would be washed out by the mechanical action of the water; therefore the more rapidly it set, the less it was subject to that action, and the more cement was retained. In his experience, Portland cement did set perfectly well under water; but with any cement, if concrete was loosely thrown into the water, the gravel would descend to the bottom more rapidly than the cement, because its specific gravity was greater, and thus concrete so used would become deteriorated in quality.

Mr. KINIPPLE remarked, that the Author had stated that "Portland cement concrete, made in the proportions of 1 of cement to 8 of ballast, in some cases, and of 1 to 6 in others, had been extensively used for the foundations of the river wall, piers of reservoir, and foundations generally at Crossness and Deptford, with the most perfect success." Now to have obtained such perfect success, it must have been absolutely necessary to have kept the entire works clear of water, for it was not possible to get good concrete under water, whether quiet, or not, if it was thrown in dry, immediately after mixing. He had ascertained that, in only 1 inch of quiet water, concrete, made in the proportions of 3 to 1, was endangered by the working out of the silicates, or the best of the cement, from the ballast; those silicates resembled slime on the surface, and, with the slightest motion, or run of water, were lost. In concreting an outer apron just inside a cofferdam at low water, he had used Portland cement concrete, in the proportions of 4 of ballast to 1 of cement. It was all put in at the same time, in the same manner, with the same cement and ballast, and by the same men, and was allowed to remain in quiet water for three months. When he had again occasion to examine it, the concrete nearest the abutments was sound and hard, but in the centre, or rather in the part last closed in, it was quite soft; in fact it was ballast, with a mere fraction of cement retained in it. This was executed in about 2 inches of quiet water, and had to be removed for the insertion of fresh concrete. To avoid this for the future, he had resolved, that all Portland cement concrete should be mixed on the surface, and allowed to set for several hours; the length of time for setting to be in proportion to the quantity of the cement used, and when set, to be used in a crumbled condition. By experiments, he found that he was able to retain nearly the whole of the cement, without any loss as to strength.

He then referred to several specimens which he exhibited. No. 1, was composed of one part of Portland cement, weighing 114 lbs. to the bushel, and one of fine river ballast; this was thrown into 6 inches of quiet water, dry, immediately after being mixed, and was submerged eighteen days, at the expiration of which time, it showed the great separation, even in quiet water, which had taken place. Specimen No. 2, similarly composed, was also thrown into 6 inches of quiet water, but not until it had been allowed to set, after being mixed, for five hours in the open air, previously to being submerged for eighteen days. This specimen was so hard, that it had to be split by a cold chisel and hammer, and had retained nearly the whole of the cement. Passing dry concrete down shoots would not prevent the separation, as the larger stones rolled out, and set the cement free. If mixed and allowed to set a day or so, it would without doubt be a success. As to the mode of executing brickwork free from a current of water, he agreed generally with the Author, but he did not think that all bricks should be thoroughly saturated with water. For tidal work, such as wharf walls, river wings, &c., Roman cement stood the 'wash' best, lias lime next, and Portland cement last. A joint was seldom lost in Roman cement compo brickwork, in lias lime mortar now and then, but in Portland cement compo there was great difficulty in preventing sometimes six, or more courses being destroyed in one tide, from the loss of the joints. Portland cement brickwork, covered twice by water in twenty-four hours, should be made with compo as stiff as it was possible to use it. The bricks should be perfectly dry, cleansed from the maker's sand, the face joints raked out for a depth of 1 inch whilst green, and pointed, temporarily, with Rochester yellow clay. The clay joints would last many days, and by the time the clay joints were washed away, the cement work would be perfectly set, and could then be pointed in neat cement. Work executed in the manner described seldom failed, and was free from many of the consequences of the running of the joints. Complaints were often made of the badness, or rather of the irregular qualities of Portland cement. He believed, in many cases, those complaints were chiefly due, to the manner in which it was applied, to uses so varied in their character. He would recommend, for all brickwork executed under water, that the joints of compo should be dispensed with, that the bricks should be coated with compo, and be allowed to set out of water some hours, and be then rubbed together in position under water. Specimen No. 3, showed nine bricks moulded, or coated, in neat Portland cement, of an average thickness of 3·16ths of an inch, allowed half an hour to set in the open air, rubbed together, into the present form, in agitated water, and kept submerged for eighteen days. Specimen No. 4, showed a better result. Nine ordinary stock bricks were coated, as before, in neat cement, then allowed five hours to set in the open air, afterwards rubbed together, under agitated dirty water, and kept submerged for eighteen days. Both these experiments went to prove, that jointless work, in almost any working depth of water, whether clear, or muddy, or where there was a great current, could be executed with perfect success. The specimens were not disturbed, from the time they were submerged, until they were taken out, when the work was found to be thoroughly sound.

The statement as to the making of a joint to a mining pump pipe, under water, at a considerable depth, was interesting, and proved what might be done with Portland cement under water. Joints might be caulked under water with cement nearly set, and broken in pieces about the size of a pea. He had frequently made use of neat cement for grouting between sheet piles, with perfect success; in one case under water, the cement in its descent, or settling down, drove out the clear water, and filled every crevice; within ten days it was hard enough to resist a chisel point. Model No. 5, showed blocks of concrete coated with compo, in the same way as the specimen bricks, guided into position by rods, or chains, built on a concrete foundation, the face joints caulked with cement, or soft wood wedges, and the chains, or light rods, grouted in with neat cement.

Mr. Kinipple added that the concrete out of which the cement had been washed, was mixed in the ordinary way. He suggested, in order to insure success, that the proportions should be accurately measured in the usual way, mixed together dry, and water added by means of a common watering-pot; the mass then turned over, and afterwards separated and allowed to remain for some hours in layers of 3 inches or 4 inches thick, exposed to the open air; and when it became so tough that it would not receive an impression from the hand, it was ready to be turned over again and passed into the water. By working it in that way he had retained the whole of the cement.

Mr. JOHN AIRD, jun., said, from the opportunities he had had of witnessing the experiments conducted by the Author, he could bear testimony to the great care bestowed on them. He believed they had been carried out in the most conscientious manner, and with every desire to do justice to all the manufacturers whose cement was operated upon. He thought there was some mistake as to the concrete being thrown in quite dry. That certainly was not the plan adopted at Deptford; for there it was previously mixed with a moderate amount of water, then thrown into the work, and in all instances where Portland cement was used it was perfectly successful. In his opinion, the quality of the cement could not be too good; but having got that, the Engineer must look to the nature of the work to be carried out, and determine the extent to which inferior materials (always more readily obtainable) should be employed. With regard to the influence of water upon cements, his experience led him to believe, that Roman cement was better suited in some few cases. For instance, for facing work to river walls, when it was subject to the rise and fall of the tide. The probability was, that even if the greatest care was taken, Portland cement would, to a certain extent, be washed away. Much better results would be obtained by the use of Roman cement, as that soon set, and became quite firm before the water rose and destroyed it.

Sir CHARLES FOX would mention an interesting instance, in which the difficulty of putting concrete into running water was successfully overcome in a simple manner. In forming the foundations of the Rochester bridge, the cylinders were sunk 42 feet below the bed of the river; being a tidal river there was in those cylinders a good deal of what the workmen called "breathing;" in other words, the water rose about a foot, at the bottom of the cylinder, and then receded, and continued to rise and fall as it was supposed by simple momentum. It was found that, as a consequence, all the cement in the concrete, when placed at the bottom of the cylinder, was washed out and came to the surface, so that for 9 inches or 10 inches at the bottom only ballast remained. The difficulty was got over in the following manner:—A quantity of concrete having been prepared, a piece of stout canvas sail-cloth, such as was used for hose-pipes, was cut one foot larger in diameter than the bottom of the cylinder. When the water subsided, the sail-cloth was spread over the surface at the bottom of the cylinder, to which it was well fitted all round, and when covered with about 2 feet of concrete, it held down the water until the remaining concrete was deposited safely upon it. In that case Portland cement was used. The same plan was adopted with all the cylinders for those foundations.

Mr. G. DINES remarked, that he had had considerable experience with Portland cement, from its first introduction to the present time, and had experimented largely, both for himself and for the late Mr. Thomas Cubitt, as to its tensile, transverse, and crushing strengths. The strongest piece of Portland cement he had tried, broke with a strain equal to 739 lbs. per square inch, the average was 558 lbs. The pieces experimented on were made of neat cement, without sand. That material was much stronger than Portland stone, which bore a tensile strain averaging 332 lbs., while Sicilian marble was equal to 1073 lbs., or double that of Portland cement. For brickwork and river walls, Portland cement was most valuable, and it was sometimes used in ordinary mortar, if the mortar was required to be of extra strength. When it was used for stucco it frequently gave much trouble, and the makers had yet something to learn about its properties. It was very different to Roman cement, as regarded expansion and contraction; and for purposes for which he had used Portland cement he was obliged to go back to Roman. Some long pieces of Roman and of Portland cement had stood in his office for some time, and he found the Portland cement, although made perfectly straight, was twisted like a piece of green deal, while the Roman cement remained perfectly true. He had seen Portland cement, where used for the coping of a wall, buckled up, so as to let the light through between it and the wall, and when he began a work with Portland cement, he hardly knew when he should finish it. He feared that it had a corrosive effect upon iron; therefore when cement had to be in contact with iron, he always used Roman.

Mr. SCOTT RUSSELL said, Portland cement had been extensively used in the insides of ships, to preserve the iron from corrosion; and after eighteen years' use, he had seen Portland cement dug out of an iron ship, when the red lead paint and the skin of the iron were as sound as on the day they were put there.

Mr. HENRY MAUDSLAY said, this fact appeared to show, that the cement had not been in actual contact with the iron, as it was protected by the red lead paint, to the extent probably of two or three thick coats. The caution raised, with reference to the effects of Portland cement in contact with wrought iron had been made upon the supposition of a fact which did not appear to exist.

Mr. **Scott Russell** observed, that the inference to be drawn from Mr. Maudslay's observation would be that, wherever cement was used with iron, the iron should be painted with red lead.

Mr. **Joseph Jennings** said, that when he had used Roman cement, where it was subject to tidal influence, it had produced sound work, although the tide had returned in five minutes; while Portland cement, under the same circumstances, had become perfectly fluid. He had used Portland cement for filling up, as concrete, between stones at the bottom of a river, and had experienced the difficulty occasioned by the cement washing out, and he had found, upon examination by divers, six months or eight months afterwards, that the Portland cement which had been put in between the stones with trunks and divers had washed out, whereas the Roman cement, with which the bottom of another lock had been repaired, when the water was out, stood perfectly well, although the water was allowed to flow over it within five minutes after the time of its being put in: yet for many purposes of construction, Portland cement was no doubt a most valuable material.

There was one point which he thought had not been quite sufficiently considered in the Paper, which was, that of the extent to which cement might be used in the form of concrete blocks, in buildings. He believed that, in a few years, a much larger proportion of cement blocks would be used for building purposes, such as dock walls, in the same way as they were now used at Dover. With this heavy Portland cement a large portion of gravel and sand could be mixed, and by that means much stronger work could be executed than any brickwork in general use; and, therefore, it was most important to consider, in what form the Portland cement could be most profitably employed in these concrete blocks, as an artificial stone for use in London. At the present time the great expense of stone was a serious consideration, but cement blocks, if large, would, he believed, almost entirely obviate the use of stone for many purposes. With regard to this point he should be glad to hear how far the shingle, which was now being used, and which to a great extent had been deprived of all angular points, had a disadvantage, as compared with the use of angular stones, in forming these concrete blocks. He was not aware that it had been used to any great extent in the form of angular gravel. The blocks at Dover and at Brighton were all formed with the ordinary sea shingle. Another point was the effect of fire upon Portland cement, when employed in the construction of furnaces of various kinds. As far as his own experience went, he thought Portland cement would stand in furnace work better than Roman cement.

Mr. **Thomas Bevan** remarked, in reference to the Tables appended to the Paper, that it would be found that the large manufacturers, in high repute with foreign Engineers, supplied cements with a breaking strain, which, although equal to the requirement, was lower than that of the firms which furnished the chief quantities to the Main Drainage Works. No hasty inference should be deduced from this. He was persuaded that the Author would be the first to admit, that those manufacturers could, if they liked, produce cement to break at a much higher strain. It should be remembered that a high breaking test could only be produced by an extra expense in the manufacture. It would cost at least 3*d.* to 4*d.* per bushel extra to break at 700 lbs. than it would to break at 500 lbs. If the Author was consequently satisfied, as was the case at first, with 400 lbs., it was not surprising that those firms, which had a full demand for their cement and a well-established business, should be content when they gave from 500 lbs. to 550 lbs.; as to have given more, would have occasioned a much enhanced cost. While on the other hand it was perfectly intelligible, that other firms should be willing to incur a sacrifice, in order to attain a higher result. As a manufacturer, he desired it to be understood, that there was no fair ground for any trade use being made of these Tables, to the disparagement of the large manufacturers. The comparison, moreover, of the breaking tests of cement of the same specific weight, but made by different manufacturers could not, within certain limits, lead to any conclusion, to the depreciation of either. Provided that he was safely above the test of the Engineer, a manufacturer would desire to make not only what would be most economical in the burning, but what would be most safe. Attention had been drawn, to the necessity of working with a maximum of chalk and a minimum of clay, in order to secure a high breaking test. But even in more moderate tests, it would be found that a different breaking strain would result at the same specific weight, according as more or less clay was used in the composition. In fact, the more clay was used without deteriorating any of the qualities of the cement, except by a little reducing the breaking strain, the 'kindlier,' to use the language of the workman, would be the cement; and the more chalk was used, within those same limits, the more 'hungry' and more difficult to work would be the cement, although it would certainly bear a higher breaking strain. It was not to be assumed, therefore, that if cements of the same specific gravity broke unequally within certain limits, that there was necessarily, any superiority, or better composition in the manufacture of either, but only that one had more, or less, clay than the other. He was of opinion, that the test of 500 lbs. in seven days was not an undue one; practically, it was little, if at all, more than the old test of 400 lbs., as that test was first used. The application of a breaking test upon any briquette of Portland cement depended altogether, upon the quantity of water used in gauging it. Working men who constantly manipulated these tests, after a time became exceedingly expert in gauging, and insensibly acquired the habit of gauging with a minimum of water. A brick made with a minimum of water, would bear a much higher strain, than one gauged with sufficient water to make a good stiff paste. Any Engineer who might doubt this experiment, would see it at once, if he tried cement gauged with two parts of sand, and broke the briquette against one similarly composed, but to which was added a good dose of water. The results, as it would tell more when sand was mixed, would be 50 per cent. wide. It was well known by those who were in the habit of supplying the French Engineers, that the breaking machine, in use by the Ponts et Chaussées and the Imperial Marine, was widely different from that employed by the Author, and at least 25 per cent. more unfavourable to the brick. It was a simple clamp, and the brick was usually broken with a jerk, by the gradual addition of weight in the most primitive manner, while the Author's machine was a regulated steelyard. Therefore, if the test was attainable upon the French machine, it would be much more so upon one so favourably constructed as the latter. The argument that a good and highly breaking cement could be made of a less specific gravity than 112 lbs. might be conceded; but that the same cement that would break well at 104 lbs. would break still higher at 112 lbs. could not be denied. He was of opinion, therefore, on the whole, that the actual test, so far from being an inconvenience or a disadvantage to the manufacturer, was a benefit, because it separated the genuine Portland cement from many counterfeits that bore its name. An objection was taken to a seven days' test, and an inquiry made if an earlier test could not be used. The Admiralty had used a test of 40 hours and 60 hours, and his impression was, that it was possible for bad cement of one particular description to pass that test—he meant over-limed cement; but certainly, none of this could pass a seven days' test. It would discover itself by defective arrises and small cracks before that time. He thought the test at seven days was the best, and that the tests of 40 hours and 60 hours were quite unsuitable for a slow setting cement. In 40 hours, and 60 hours, cement of 104 lbs. to the bushel would perhaps break as well as cement of 112 lbs., but it was in the longer dates that the superiority of the heavier cement was to be seen. If it was suspected, that cement was over-limed, and if it was desirable to form a judgment before seven days, a small pat gauged neat might be put in water, immediately after it was set, and left unprotected. The thin edges would fly much more quickly, in this way, than would be the case in a brick in a mould. It was interesting to hear, that Portland cement withstood a higher strain than the materials for which it was used as mortar. It would seem, that the argument that such excessive strength was unnecessary, should give way to the consideration, that with the possession of good cement—cement stronger than the materials —it was time to procure better bricks and better materials.

Mr. J. A. LONGRIDGE said, a question was raised, in reference to the use of salt water, in slaking cement and lime. He had been accustomed, for years, to use sea water for that purpose, and had always found it succeed, quite as well as fresh water. He had also largely used sand of the sea-shore, impregnated with salt, and he had found the lime set as well with that, as with other sand, provided it was sharp sand. But a more interesting case was that which was being carried out at Port Said, in connection with the Suez Canal. The last time he passed through Egypt he was informed by one of the Engineers, that salt water was being used for slaking the lime, and that sea sand alone, and without any gravel or stones, was being employed for the concrete for the piers. It was a bold experiment, but it appeared to be exceedingly successful. He had since received from M. de Lesseps a copy of the specification, according to which the concrete was made, accompanied by a letter, stating that sea water was used exclusively, copies of which are annexed. The blocks were about 11 feet 6 inches long, by 5 feet by 7 feet, and they were required, by the specification, to be made two months before being immersed. The work done, amounted, on an average, to about 220 cubic yards per day.

(Copy.)

" Renseignements sur les jetées de Port Saïd.—No. 5968.

" MONSIEUR, *Paris, le* 26 *Décembre*, 1865.

" EN réponse à la lettre que vous avez addressée le 22 courant à M. le President de la Compagnie, j'ai l'honneur de vous addresser ci contre, un extrait du marché que nous avons passé avec M. Dussand frères pour la construction des jetées de Port Saïd, extrait qui répond à la plus grande partie de vous questions.

" Je dois ajouter pour completer ces renseignements que le ciment est traité à l'eau de mer exclusivement, et que nous immergeons par jour, environ 170 mètres cubes de blocs de béton.

" Agréez, Monsieur, l'assurance de ma considération distinguée,

(Signed) " CADIAT.

" L'Ingénieur, Chef du Service de Paris, à Monsieur James Longridge,
Abingdon Street, No. 18, Westminster, à Londres."

" EXTRAITS du Marché Dussand pour l'exécution des Jetées de Port Saïd en Blocs artificiels.

" Les jetées à construire doivent avoir, celles de l'ouest, une longueur d'environ deux trois mille trois cents mètres ; celle de l'est, une longueur d'environ deux mille mètres.

" Elles seront construites sur le même profil, lequel présente un couronnement horizontal de cinq mètres de largeur, emergeant de deux mètres au dessus du niveau moyen de la Mediterranée, avec des talus à quarante cinq degrés.

"Les blocs auront trois mètres quarante centimètres de longueur, deux mètres de largeur, et un mètre 50 centimètres de hauteur, soit, déduction faite des rainures un cube de dix mètres.

"Une partie du massif des jetées pourra être faite avec des blocs de quatre mètres cubes, sous la condition expresse que les revêtements extérieurs seront composés exclusivement de blocs de dix mètres.

"Les blocs de l'une et l'autre catégorie seront formés de sable de la plage et de chaux du Theil, dans la proportion de 325 kilogrammes (325 kls.) de chaux en poudre sèche pour un mètre ($1^{m.}$ 3) de sable. La Cie. se réserve le droit de faire varier le dosage de la chaux jusqu'à concurrence de vingt-cinq kilogrammes (25 kls.) en plus ou en moins de la proportion indiquée.

"La chaux proviendra des fours de M. Savin de la Farge au Theil (Ardèche), ou elle sera de toute autre provenance, donnant une chaux de quantité egale et acceptée par la Cie. Toutes les envellopes porteront la marque du fournisseur.

"Les blocs demeureront soumis à la dessication à l'air libre pendant deux mois ou moins, sauf les réductions de delai qui pourra autoriser le Directeur Genérale des Travaux en cours d'exécution."

Mr. Longridge added, that Portland cement was not used at Port Said, but a hydraulic lime brought from Theil, in Ardèche—a lias lime, he believed, but the specification gave the name of the manufacturer. His own experience, had been chiefly with hydraulic lime, and coral lime which had no hydraulic properties, and with the latter he had used sea sand for outside work, and found it to set well.

Mr. Scott Russell said, he had been requested to inquire what was the kind of sand, with which the cement was mixed? He did not put this question from any impression of his own, it was suggested to him by Mr. Harrison, who had had great experience in the use of cements, and who said that, according as the sand used with the cement had been formed by the sea, from one substance, or another substance, he got most variable returns; and that, what was called Thames sand was mainly the sand of flint, and on the other hand, the sand found on the western coast was, to a great extent, formed from limestone. It was, therefore, obvious, if a fine sand formed from limestone was mixed with cement, the result would be different from that of sand which was formed from flint. He would ask, whether any experiments had been made, in which the quality and nature of the sand had been examined, as closely as the quality and nature of the cement?

Mr. Cockburn Curtis said, his experience and observations led him to believe, that great advantage was derived from mixing the mortar, cement, or concrete, intended to be used in submarine, coast, or estuary works, with salt, or brackish water, of the same character as that, in which the works would eventually be submerged. The minute component elements of salt water had not yet been ascertained with the degree of precision which was essential in forming a correct theory on this branch of the subject; but able chemists had asserted, that it contained small proportions of acids, and it was probably by those acids, that the mortar and cement, if mixed with fresh water, were acted upon, when submerged. The difference in specific gravity, between fresh and salt water, although small, was of sufficient importance to be taken into consideration. Fresh water rocks frequently became disintegrated when exposed to the chemical action of salt, or brackish water, and for that reason, he considered it desirable, in the construction of such works in béton, or concrete, to use the sand, shingle, or other materials found on the foreshore, or beach, from which the particles subject to the chemical action of salt water had already been removed.

Mr. **Vignoles** said, that more than twenty years ago, French Engineers employed salt water in making concrete blocks for Algiers, but many of those blocks (whether from the fact of their having been formed of concrete mixed with salt water, or from some supposed chemical action of the waters of the Mediterranean), had become disintegrated, and considerable destruction had taken place, though the great mass still remained in position. At the new port of Marseilles salt water was used for the concrete blocks, with greater success. It was, therefore, of no recent application. He would observe that, having been, on more than one occasion, compelled, in foreign countries, to make his own hydraulic cement, he found the great principle of perfection was drying the clay as much as possible, either in the sun, or by artificial means, previous to baking it. Having dried it in a more perfect manner than was generally done, the degree of baking was regulated to be as little as possible, done slowly, and only just sufficient to accomplish the object, without affecting the properties of the clay. When so burned, the material could be reduced under rollers to an impalpable powder; used in that state, it was most successful, and the specific gravity was higher than if it had not been so perfectly treated. A scientific reason was thus afforded in favour of weight, because the specific gravity became a test of the good burning and preparation of the cement.

Mr. C. B. **Lane** remarked, that the axiom " no chain is stronger than its weakest link," was an established mechanical principle, and that the argument based on that principle had not, he thought, been answered. It occurred to him that if the Author, in making these experiments, had supplemented them with a series of experiments upon pieces of brick clay, cast in the same moulds, and properly burnt, he would, so soon as he had arrived at equality of cohesion between the brick and the cement, have solved the question not only mechanically, but also commercially and economically; and any expenditure for procuring a material beyond the cohesive strength of the brick was so much labour lost. Having arrived at what might be called an equation of values, to endeavour to increase one side of that equation, without increasing the other, appeared to be incurring an expenditure which was hardly justified. With respect to the argument of competition, more than one of the great cement-makers had stated, that they had not supplied cement for these works. It, therefore, appeared, that the limits of competition had been rather narrowed than widened, by the processes followed. The great prospective advantages that were anticipated, and which would in all probability be obtained, when they did accrue, would be for the benefit of future works, but not for the works which had paid for them. With respect to the relative merits of blue lias lime and Portland cement, he thought that a great portion of these works might have been constructed with blue lias lime; at the same time it might be argued that it was all-important, in the streets of London, to use a material which would lead to the completion of the work with the greatest rapidity; but there were many districts, in which blue lias lime might have been substituted for Portland cement (perhaps in most cases for concrete), with a considerable saving of expenditure.

Mr. F. J. BRAMWELL thought that a humble view had been taken of the duties of Engineers in high position, when it was argued that it was not a part of that duty to experiment for the benefit of posterity. For his own part, he believed an Engineer eminent in his profession, and intrusted with large and important works, could not do better service than to endeavour to raise the standard of work carried out under his directions; and those who had inspected the character of the work executed under the superintendence of Mr. Bazalgette and Mr. Grant, must acknowledge that those gentlemen had raised the standard of work in such a manner as to deserve the thanks of the profession.

With regard to cement, he thought it one of the most important subjects that Engineers connected with structures in brickwork could consider, because clearly there was no use in having good bricks to build with, unless they had also good means of fastening them together, that was to say, one great difficulty Engineers had to contend with, was the means of attachment of the material; therefore he thought time was well bestowed upon the consideration of the question. Mr. Grant came before them with so many years' experience, and with the results of so many thousands of experiments, that it was almost impossible for anybody, except those who had been engaged in the manufacture, and had been in the habit of making daily experiments, to speak with any confidence on this subject, in the face of the numerous experiments which had been made by Mr. Grant. That gentleman had stated in effect, that there were three tests which the cement must satisfy before it could be pronounced to be thoroughly good; one as to strength at various ages, neat and mixed; the second as to the power of resisting water; and the third, the test of weight per bushel. The latter test was the only one as to the propriety of which any difference of opinion had been expressed. For his own part, he would say as soon as he heard of the test by weight, he was struck with the difficulty of correctly ascertaining what the weight was, because he knew by experience, that when dealing with granulated matter, it was almost impossible even with the greatest care to get uniformity of condition in the respective trials, that was to say, to get the same amount of such granulated material into a particular measure. In corroboration of this he would state the results of what he had tried lately. A quantity of cement was poured into a bushel measure by a man accustomed to the work, and struck off level. It then weighed 107 lbs., exclusive of the weight of the measure. Then another portion of the same cement was poured slowly out of the sack down an inclined board into the bushel measure, and it then weighed only 97 lbs.; he then had it shaken down in the measure, and the weight then got up to 132 lbs. When it was found, therefore, with the same measure of capacity and with the same material, there could be a variation of from 97 lbs. to 132 lbs., he could not help thinking if a test of gravity could be obtained which was not liable to those variations, it would be a very desirable thing. Until the mode of ascertaining the weight was altered so as not to be affected by the question as to whether, in the trial, the cement was more or less compact in the measure, he thought that the stipulation as to weight—though probably the manufacturers did not wish to have any more tests imposed—should be combined with that of sifting, so as to insure the fine grinding of the cement, as if this were not done, he thought the requirement as to weight was liable to act as a premium for coarse grinding. In reference to this, he would state that he had sifted through a sieve with 900 holes to the square inch, a certain portion of the cement which weighed, as before stated, when very carefully put into the measure, 97 lbs., and when put in the ordinary way, weighed 107 lbs. to the bushel: those portions which would not go through the sieve were then poured into the bushel measure with the same care as that which made the unsifted weigh, as previously stated, only 97 lbs.; with this care the coarse weighed as much as 101 lbs., and when shaken down hard into the measure, 144 lbs., whereas the unsifted cement weighed, as before stated, only 132 lbs. He then took by themselves the fine particles which had passed through the sieve, and they then weighed only 98 lbs. as against 97 lbs., and, when shaken, 130 lbs. as against 132 lbs. for the mixed and 144 lbs. for the coarse. He gathered from this that weight, as ascertained by pouring the material into a measure, was liable to extremely variable results, even when the greatest care was taken; and further, that unless it was accompanied by the test of sifting, there might and probably would be, badly ground cement present in the mass. That being so, and agreeing as he did in the importance of the test of weight, it occurred to him that a means of ascertaining the true weight for cement might be adopted similar to that which was employed for ascertaining that of gunpowder, and which means had been shown to him by Mr. Abel, of Woolwich Arsenal. The mode pursued in ascertaining the gravity of gunpowder was in effect this:—A vessel capable of containing a known weight of mercury was employed. Then a known weight of gunpowder was taken and put into the vessel, and thereby a bulk of mercury equal to that of the grains of gunpowder was displaced, and this exact bulk could be ascertained by the diminished weight of the bottle. Thus, the weight of the cement having been known, and its bulk ascertained, its specific gravity was at once determinable. Mr. Abel kindly allowed one of Mr. Bramwell's assistants to use the apparatus to test the gravity of cement; but it was found that the liquid used—viz., mercury—was not suitable as a test for so finely powdered a material as cement; but by using turpentine as the liquid, the gravity had been ascertained without difficulty, and he found the specific gravity of the cement before mentioned, which, as put into the bushel measure, weighed, as before stated, the 107 lbs., was 3·11. Now 3·11, it would be found, was equal to a weight per bushel of 249 lbs., so that if that cement could be obtained in a really solid state, it would weigh 249 lbs. instead of 107 lbs. 120 lbs. cement was equal to a specific gravity of only 1·5, and 104 lbs. was equal to only 1·3 as it lay in the bushel. The way in which the gravity was taken was this:—A phial holding, when filled to a certain point, a known quantity of turpentine was taken, and a certain weight of cement was put into it. It was then filled up to the marked point; the contents were weighed; and the excess of weight found was clearly that which was due to the weight of the cement, above that of the turpentine which it displaced, and in that way the gravity was ascertained. Whether it would be possible to employ so refined a test as this in practice, he was not prepared to say. He thought Mr. Grant would tell them it was not.

Then came the next question, which was, whether this insistance of great weight in cement was not likely to lead to trouble—whether there ought not to be some limit put to it? The manufacturers said, if they were bound to produce cement of great strength and high specific gravity, it would cost them more to make it, and they argued that it was better to use a weaker cement with a less admixture of sand, than a stronger cement obtained at a greater cost with a larger admixture of sand. The heavy cement was obtained by hard burning; and when that was carried too far, it was likely to cause the cement to fuse into a vitrified mass, which was of no use whatever. To prevent that, it seemed there was an excess of chalk added, and if the chalk were not properly burned, there was danger of that original defect of Portland cement, viz., that after it was thought to have been set, it 'blowed,' from the lime not having been fully acted upon in the burning. Therefore it was well to see whether this 114 lbs. to the bushel was not as high a specific gravity as was required, and whether the 120 lbs. was a thing to be sought after; because he could understand that an Engineer, finding that the weight had been gradually raised from 110 lbs. to 112 lbs. and 114 lbs., and that 120 lbs. was attainable, might, in the desire to do the best, put into his specification cement of 115 lbs. to 120 lbs. weight per bushel, and by so doing might do harm instead of good. There could be no doubt that heavy cement set very slowly—not that at the end of a week it had not great tensile strength, but that at the end of an hour it was not in a condition to resist water so well as a lighter cement. He might say, in passing, with reference to the most desirable quality of cement for hydraulic works, that the material which was left behind out of the cement, after sifting through a sieve with 36 holes per linear inch, would not set at all. After several days it crumbled like sand; and he thought it would be well if chemists would determine whether that difficulty in setting arose from a difference in the constituents of the larger and harder particles, or merely from their having escaped the action of the millstones. He had found, even after pounding these particles fine enough to go through the sieve, that often, if they set at all, it was in a very poor manner.

The next point was as to the amount of water used in gauging the cement for these experiments. He found, as a rule, that about one-fourth part by weight of water was the least quantity that would gauge the cement. If the cement were very quick setting, or if it were very fine, it could not be gauged with so little water as that; that was the least that could be used with hard-burnt weighty cement. He had been curious to see what the effects would be of gauging with different quantities of water, and he found if only one-third weight of water were used, a sample would break at the end of ten days with 244 lbs., while if one half the weight of water were used, the sample broke at the same period at 90 lbs.

Then he found that the resulting weight was nearly that of the mixed materials. Taking an equal weight of cement in all cases, viz., 30 oz., and mixing with 9½ oz. of water (which was the lowest quantity he could use), then with 10 oz. and then with

15 oz.; then pouring the mixture into square boxes 2 inches square, the smaller amount of water gave a resulting bulk of a height of 8 inches, the next of 8½ inches, and with half water it gave a height of 10 inches. This showed that there was great temptation to use water largely, as it went to make bulk of the finished cement, although it was at the expense of its cohesive powers.

It had been stated in the Paper that it was important care should be taken as to the amount of water used in the gauging; but it had not been stated what proportions of water were used in the experiments. Mr. Bramwell might state that in his own experiments, the specific gravity of the block made from cement mixed with half its weight of water was only 1·83 (that was taken at the end of four days), whilst the specific gravity of that mixed with only one-fourth weight of water was 2·25.

A suggestion had been made as to whether they were thoroughly acquainted with the different kinds of sand mixed with the cement when those two materials were allied together. In one of his experiments he took well-washed sand from the Thames, and in another some pounded Portland stone, the sand and the pounded stone being both sifted through the same sieve, and there was no doubt as to the superior strength of the cement block mixed with the pounded Portland stone; but he could not give the results with particularity, because a sufficient time had not elapsed to show the full effect, but it was evident the Portland stone was considerably the stronger of the two. As regarded the way in which sand set with cement, it was desirable to know what changes took place after a block of this kind had set. He presumed, in the case of lime, that if they used lime alone they got very bad mortar, but that when mixed with sand it operated chemically upon the lime. The necessity for sand did not, however, exist with Portland cement, as that was strongest without any mixture of sand. It was a question whether the sand acted chemically, or merely as a means of filling up the spaces; if the latter were the case, he could understand that the larger grained the sand was, the better it was for the purpose, even irrespective of its being clean; for he believed, with large particles they had less cubical contents of interstices than with small, as small particles did not lie much closer than large ones, so that the thickness of the interstices to be filled was nearly the same in both cases, while the area of the interstices was much greater in small particles than in large. A question had been raised with respect to cement placed in contact with iron, which turned out to be a question of cement upon oil. He might say, that having occasion to form a deck upon a floating dock, which deck he did not wish to be combustible, so as to be in danger if a hot rivet fell upon it, nor to be liable to rot if temporarily immersed in water in a tropical climate, and which therefore did not admit of the use either of creosoted or of unprotected timber, he had made every inquiry he could as to the behaviour of Portland cement concrete in contact with iron, and he was now having prepared a Portland cement deck, 3 inches thick, but he was afraid that experiment would not settle the question at issue, because, after all, it would only be cement upon oil, all the iron having been steeped in oil when hot.

It had been suggested, that there were great probabilities of cement, with a large admixture of sand, being used as a substitute for bricks. There was no doubt that good bricks had attained to an extraordinarily high price. From the Paper, it appeared that the resistance to crushing of bricks, except the very best gault bricks, was 5 tons, while with proportions of one of cement to five of sand, the resistance was on an average 12 tons. It was clear that in respect of crushing the cement bricks were far better than the ordinary run of bricks; so much so, that he presumed it would be practicable to economize the material by making perforated bricks; but even if they were made solid, he calculated that at the present time they would cost 41*s.* 6*d.* per thousand. If the use of cement were still further economized, so as to bring down the power to resist compression at six months to that of ordinary bricks, there was some prospect of the cement brick being able to compete successfully with ordinary bricks.

Mr. J. B. REDMAN said, he thought there was force in the remark, that it was better to arrive at a high standard value for cement, than to keep it down to that of the material to be attached. At the same time, it occurred to him, that the value of the artificial material, as evolved by these experiments, compared with some of the natural stones, gave a very high value to the former, and a very low value, in some cases, to the latter. Looking to the comparisons of Portland cement with Portland stone, the Author's tables gave the power of resisting crushing weight of the latter, as only 167 tons per superficial foot, while Barlow gave a value of 294 tons per superficial foot. Some experiments were made two years ago, by a Committee of the Royal Institute of British Architects, and, in testing the relative merits of Ransome and Co.'s, and M. Coignet's cements, and other materials, they found Portland stone gave a value of from 240 tons per superficial foot to 326 tons. It was clear, therefore, there was a wide difference between the observed results as to the value of Portland stone. As regarded the results brought out for the artificial material, Mr. Grant's experiments gave to the Portland cement, a crushing power of 412 tons to the superficial foot, while Mr. White's Paper,[1] read some few years back, gave only from 146 tons to 160 tons, as shown by experiments made at the International Exhibition. This had relation to crushing power. It had been suggested that Roman cement might be usefully employed in tidal works in getting in deep foundations, and he might refer to a work, which he carried out at East Greenwich twelve years back, in which a heavy river wall, subject to the tide twice a day, was put in without coffer-dams. That wall, which had been perfectly successful, was built in Roman cement, faced with rough Guernsey pitching blocks, which had the property of resisting vegetation. A few years after that he built another wall, on the opposite side, in blue lias lime, on a base of concrete of blue lias lime, also without coffer-dams, and that was equally successful. He had also used concrete made with Roman cement, in excluding the water at a great depth below low water, in a rapid tideway, in the bottoms of cylinder foundations.

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[1] *Vide* Minutes of Proceedings Inst. C. E., vol. xi. p. 478.

Mr. J. F. **Bateman**, on the subject of hydraulic cements and mortars, would state the mode of construction adopted by Mr. Stoney for the Ballast Board at Dublin, for quay walls at that port. The ordinary quay walls were of concrete, formed of one part of Portland cement, to ten parts of the gravel of the Liffey. The crushing power, at three months, was 16 tons to the square foot, and this concrete was made at a cost of from 10*s*. 6*d*. to 10*s*. 8*d*. per cubic yard when set, exclusive of the cost of plant. It was not set in blocks, but was deposited between planks, in the ordinary way of making concrete walls. Owing to the success of those walls, Mr. Stoney had undertaken the formation of concrete blocks, on a larger scale than, he believed, had been hitherto attempted, in the building of a wall 24 feet below low water, without coffer-dams. These blocks were made 23 feet upon the base, 26 feet deep, and 10 feet upon the face, weighing 330 tons each. They were built on a strong platform formed on the shore, to carry this enormous weight, and were allowed to remain as long as was necessary to harden before they were removed. They were then floated to their destination, and lowered to the base previously prepared for them, under a large diving bell, 20 feet square. The cost of these blocks, formed of one part of Portland cement, to six parts of the gravel of the Liffey, and faced with granite, was estimated at 16*s*. per cubic yard, exclusive of plant, and at 18*s*., with plant. In fine weather, they might be laid on an average of one block at every tide; but by supposing, that only one block could be laid every other day, or 150 blocks in the course of the year, they would form a wall 1500 feet long, at a cost which was a mere bagatelle, compared with other modes of construction, involving the use of coffer-dams. It was about ten months since he investigated the question, and he could not report what had been done since. He could, however, speak with confidence as to the stability, strength, and apparent durability of the walls already constructed—those in which the composition was one part of Portland cement to ten parts of the gravel of the Liffey.

Mr. R. P. BRERETON said, doubts having been expressed as to the advantages of the use of Portland cement in water foundations, if passed through water, either running or still, he would state that he had had opportunities of using it very largely under the latter condition. About seventeen years ago, when Portland cement was first thought of for foundations, inside of cylinders, the late Mr. Brunel was employed in building a bridge, across the Thames at Windsor. It was, at that time, stated that Portland cement answered well, used in the proportion of one part of cement to ten parts, or twelve parts of gravel, and in that way, formed an economical mode of filling up foundations in the water. In putting it in through water it was not considered prudent to try it in those proportions, but it was tried with one part of cement to nine parts of ballast. The cylinders were sunk through the gravel without pumping, and they became full of water through the bottom, and under the sides. Through that water the concrete was passed, after being properly mixed, and it set hard and well in eight days, or ten days. The result of the first experiment was surprising. On pumping out the water, there was, on the top of the concrete, a thin layer of slime and matter, which led to the expectation that the cement had been washed out of the concrete, in its deposition, and for satisfaction on that point the concrete was carefully examined. It had set very hard, and on drilling nearly 3 feet into the concrete no amount of drilling, consistent with reason, could make any further impression. This proved that the slime was due to only a very small portion of the cement that had been washed out, and that the great bulk of it remained in the concrete: the proportions were afterwards increased to 1 to 6. The result of the experiment led to the use of that concrete very largely, in subsequent bridges, and it was deposited in depths even of from 50 feet to 70 feet, without the least attempt at pumping. When sufficient concrete had been deposited to balance the water pressure, and when, after ten days, or a fortnight, it had set, the water was pumped out of the cylinders, and the remainder was filled in with concrete of the ordinary kind.

Those instances were sufficient to prove, that concrete was good for all purposes so required of it. Those foundations, which had been built sixteen years or eighteen years, showed no symptoms of failure. With regard to the setting properties of this cement, when used with sea sand, or otherwise, he had found the use of sea sand and salt water perfectly satisfactory, both with Portland cement and lias lime; but there was no question as to its setting being rather retarded by that course. A few weeks ago, at some works in Wales on which he was engaged, in a tide-way, he used cement mixed with sea sand and salt water, but it did not set quickly enough. He then tried the blown sand, taken from the hills, not wet, and mixed with fresh water, and the cement set satisfactorily, whereas if the sand was saturated with salt water it took a longer time to set. In the case of lias mortar, so long as it was not subject to the wash of the sea, it might be covered with water ten minutes after it was put in, and would set perfectly well, but not so quickly as if used in the dry state.

Mr. FOWLER, President, inquired whether, in passing the concrete through deep water, wooden spouts were used for the purpose; and whether Mr. Brereton's remarks, as to the comparative speed of setting of cements mixed with sea water, and of those mixed with fresh water, had reference to works under water or above the surface?

Mr. BRERETON replied, that at Windsor, with a depth of 12 feet to 18 feet, the concrete was lowered in bags, holding about 1¼ yard at a time, and it was discharged at the bottom. The same plan was adopted elsewhere in deeper water upon a larger scale, but a different disengaging apparatus was used. The result of his experience as regarded the speed of setting was, that the cement did not set fast enough before the tide rose, when saturated sea sand and salt water were used. The work referred to was that of the invert of a dock entrance. It was put in when dry, but the tide rose before the cement had time to set; with the blown sand it set in half an hour.

Mr. JOHN COODE submitted, that the average results given in the Author's tables, if taken without reference to the extreme results, were calculated to mislead. The Board of Works test was 500 lbs. on the briquette. Now 500 lbs. might be a mean, or an average of 499 lbs. and 501 lbs., so would it be also a mean of 1 lb. and 999 lbs. It would be desirable to ascertain, what proportion of the cement of each maker had been below or above the required standard, and in what degree, so that the degree of superiority which the cement of one maker possessed over that of another might be known. There appeared to be an extraordinary range in the results, varying from 75 lbs. to 719 lbs. (Table II.) He thought it desirable also to have some experiments made on the relative strength of concrete formed with Portland cement and of that made with blue lias lime. (Table XLI.) He quite agreed that probably Portland cement would be used much more extensively than it was at present. Hitherto this cement had been rather dreaded. He was so satisfied with it, that he had, some twelve months since, specified for the construction of a pier, facing the German Ocean, and exposed to the 'fetch' of a sea of from 190 miles to 200 miles, the whole of which, from the foundation courses upward, was to be of Portland cement concrete blocks, the face of the work, both seaward and towards the harbour, being of the same material, and he believed it would prove, both in point of strength and durability, to be equal to any ordinary building stone. In point of cost, it involved the question of building the pier in that material, or not at all, for if the pier had been faced with stone, the expense would have been beyond the funds at the disposal of the authorities of the harbour in question. He was led, in a great measure, to adopt that material in the face of the work, from having seen the result of the action of the sea upon a pier at Hartlepool. Some of the members might be aware that, in the year 1856, a pier was projected in Hartlepool Bay, which was stopped somewhat abruptly by Act of Parliament, and the work was left with the bare ends, both of the face-stones and concrete blocks in the hearting, stepped back in the ordinary way. He examined it after seven years' exposure to the action of the sea, and he found that the arrises of the Portland cement blocks—though they were not of first-class quality—were quite as sharp as those of the Bramley Fall stone with which the pier was faced. He had the authority of Mr. James May for saying, that the experience of more than fourteen years, at Alderney, had shown, that the blocks of concrete, made with Portland cement, indurated with time, rather than disintegrated. This seemed to be a reason for making experiments upon the relative strength of concrete made with Portland cement and with different proportions of shingle and sand. He would also observe that, amongst all the experiments made with that cement, he was not aware of any having been made with reference to its resistance to the action of attrition, or abrasion. That was a quality which Portland cement possessed in a remarkable degree, and experiments in that direction might be worth the attention of manufacturers, and would, he anticipated, exhibit some extraordinary results, which would be very useful, and encourage the larger use of the material. Sea walls, or piers faced with concrete blocks, and exposed to heavy seas, would not only have to resist the shock of the waves, but also the severe test of the attrition due to the moving sand and shingle, which were always found to tell considerably upon such works, at the ground line in shallow water, and this was one of the greatest enemies to contend against in works so founded. In reference to the remarks upon the relative strength of test blocks, when made with different descriptions of sand, it had been stated that, in one experiment granulated Portland stone had been used as sand. The strength in that case depended upon mechanical adhesion, due to the porous and absorbent character of the material used as sand. Some years ago, he had cemented together a pair of granite blocks, a pair of Portland Roach blocks, and a pair of blocks of ordinary Portland stone, all of the same sectional area, and he had found the relative amount of adhesion to be represented by eleven, in the case of the granite, twelve, in the case of Portland Roach, and sixteen, in the case of the ordinary Portland stone—results, which he believed to be, simply in ratios corresponding to the porosity of the different stones.

His experience with Portland cement, for works in an open tideway, had not been altogether satisfactory, and he could not agree that it could be used for all purposes in a water-way. He first tried it about twelve years since, in attempting to set some large ashlar stones in a tide-way, at about eighteen inches above low-water level. The blocks having been set, and a mere ripple—not to call it a wave—coming upon them, the cement was fairly pumped out of the joints. That, perhaps, was the strongest test to which a cement, or mortar joint could be exposed, viz., the kind of pumping action which kept the whole body of cement in motion, and that action was more destructive in a straight ashlar joint, than in rubble masonry. With regard to the export of Portland cement, the best and cheapest mode of conveyance on long voyages, was by packing it in wrought-iron tanks, measuring about four feet each way, as a convenient size, instead of in casks. Thus protected it always arrived at its destination in first-rate condition. He had, on several occasions, sent cement in that way to some harbour works he was executing without a contractor in South Africa. It resisted all moisture and damp on the voyage, whether from leakage of the vessel, or any other cause, and the iron tanks had been sold in the colony, generally for the same money, and, in some cases even for more, than they had cost in this country.

Mr. BRERETON explained that he had never used Portland cement concrete in a tide-way; but in deep still water he had done so.

Mr. JOHN HAWKSHAW, Past-President, said, he had used Portland cement in a tide-way, and had not experienced any difficulty in so using it. Neither had he experienced difficulty in using concrete blocks in similar situations. In positions where the water was rough, he took the precaution of immediately pointing the surface joints with Medina cement, which set very rapidly. As to the setting of concrete in water, he had passed it, by means of boxes, through 70 feet of water, and with the usual precautions it succeeded. In Italy he had seen sea walls built in 20 feet of water, without passing the concrete to the bottom in boxes. Nothing more was done than to mark out the outline of the wall, by piles boarded on the sides. It was mixed very rapidly, and a large number of men and boys were employed to carry it away in small quantities, and throw it where it was to be deposited. Extensive sea walls were built in the Mediterranean in that way.

There could be no doubt that within his own experience, the manufacture of Portland cement had been greatly improved, and it could now be relied on to an extent which could not have been done formerly. Therefore he could quite understand how the tests had been increased from time to time. He had so much confidence in it, that he was now commencing a large harbour on the Dutch coast, at the mouth of the Amsterdam Sea Canal, the piers of which were to be carried out a mile and a quarter into the sea, and he proposed to build them of blocks of concrete made with shingle and Portland cement. He agreed that these blocks, when well made, appeared to retain their forms and preserve their surfaces equal to those of any stone which was used for these purposes.

With regard to the experiments where, by using a larger proportion of water, larger-sized cubes were obtained, he did not think they could be taken as a safe criterion, unless a considerable time was allowed for the concrete to dry. He did not gather that this had been the case; for there could be no doubt that cubes made of Portland cement and sand did go on improving for a considerable period. Some such cubes were in the room, which had been made ten years ago, and they had evidently hardened with time; for he had lately made similar cubes and compared the two. Those he had made were of the finest sand (similar to that of the Dutch coast) and Portland cement, varying in proportions from 1 in 4 to 1 in 10. He believed blocks made in that way, could they be given time enough, would answer in some situations. The difficulty in using sand and cement arose from the fact that blocks so composed took a long time before they could be handled. The fact that no shingle was to be found on the coast of Holland, had caused his attention to be directed to the use of sand alone for hearting or internal blocks. Since he had visited the Suez Canal, he had been informed that there was some idea of making the piers, at Port Said, of blocks of sand and cement only, and, no doubt, where there was time to wait till these blocks became hard, they would be suitable for portions of the work. Portland cement had the remarkable quality, that it indurated to a higher extent in water than in air. That was in itself a great advantage in sea works. One thing which gave him confidence in adopting concrete blocks so extensively as he had done, was what he noticed some years ago at ports on the Mediterranean. He endeavoured to ascertain the age of some concrete blocks which he saw in an old pier at one of those ports, not built, but thrown in as *pierre perdue*, and, as far as he could make out, those blocks had been made about

100 years. They were not perfect in form, but they had not been made with the care with which blocks were made at the present time for works of that kind.

As to how far Engineers should stop short of securing the best material they could get, of course that was a question which could not be solved by any specific resolution. If they had only a little money, they must make the most of it, and buy what materials they could afford. The Metropolitan Board of Works had plenty of money, and a large constituency to fall back upon, and they were not to blame for having tried to secure the best kind of work. The Author of the Paper had made numerous and careful experiments, and had presented them in a clear and lucid form; at the same time it would be a mistake to suppose, that this was the first extensive use of this material, or that the experiments were very new. Many Engineers had used Portland cement for years, and many had made careful experiments with it. He agreed with the Author, that weight was a test of quality, though that test alone could not be relied upon.

He had used lias lime extensively, and had found that, when exposed to sea action, and when mixed with pozzolana, it sometimes softened to a very small extent upon its exposed surface. This fact would not be discovered unless the surface were examined minutely. In the interior of the work, it would be quite hard; but, where it was exposed to the sea, a thin film would be found softened by the sea water; he had not yet observed that Portland cement was so affected: whether it was in consequence of using pozzolana, he could not say. With regard to pozzolana, it was, he thought, in many cases, a mistake to apply it to hydraulic limes. It was much esteemed by the old Engineers, who knew that the Romans used it to a great extent, and their works were regarded as being of a very enduring character. He had taken the pains to examine almost every important work in Italy. He had seen most of the aqueducts, and he found that pozzolana was always used; but the Italians mixed it with common white lime, and with that lime, it made a good mortar; but he was inclined to believe the combination of pozzolana with hydraulic, or lias limes, was not in every case beneficial; and it would be better, where good lias lime was to be had, to leave out the pozzolana.

Mr. E. **Druce** referred to the specimens which showed the results of Portland cement mixed with different proportions of sand up to 1 to 10. These specimens were mixed by himself just ten years ago, and were, he thought, of special interest, as showing the cement in its ultimate state of hardness. There was also a piece of a Portland cement block, which bore upon the point alluded to, as to the abrasion of Portland cement concrete by shingle, it having formed, during a period of six years, the outer corner of a sea-shore groyne on the coast of Sussex, round which very large quantities of shingle had been constantly passing. It was part of an ordinary Portland cement concrete block, made in the proportions of one part of cement to nine parts of shingle and sand. The abrasion had been very slight, and the cement had showed no signs of weakness, nor had any stones been displaced. He would now direct attention to the appeal of the cement manufacturers in behalf of light cement, as against heavy, or more highly manufactured cement, the statement being, that cement of 104 lbs. to the bushel was, for all practical purposes, as good as that of 114 lbs., and a table of results was brought forward in proof of that assertion; but the comparison, as made in the table exhibited, was between 104 lbs. and 112 lbs., and not between 104 lbs. and 123 lbs., which latter was the subject of the table prepared by the Author, and with which the results obtained from the light cement bore no comparison. The latter was the class of cement that was used in the works at Dover, the average of the cement employed there being 124 lbs. to the bushel. It was further to be remarked, that the comparison in Mr. White's table was between cements of only thirty days old, and it was no doubt wished that the inference should be drawn, that the ultimate strength would follow in the same proportion. He apprehended that it was the ultimate strength of cement, and not that at its earlier or intermediate stages, which concerned Engineers. A comparison, however, of the properties of these cements would explain how this apparent equality in results had been obtained, and also why the heavier would give an ultimate result far better than the lighter quality. The light cement of 104 lbs. had the property of quick setting, and showed good results in the first instance, but it arrived at its state of ultimate hardness at a comparatively early period; while the heavier cements showed moderate results at the earlier stages, but continued the process of hardening, at a rate much more in proportion to their age; the period for arriving at their ultimate hardness being also much longer, as shown by the Author's table, which stated it to be from one year to two years. The results of 400 experiments made by himself on each of these classes of cement satisfactorily proved the superiority of the heavy cement, and that the inference sought to be established was entirely fallacious. These results had been fully borne out in practice on the works at Dover, by the quality of the concrete blocks, and in other ways, and the contractors were so satisfied that it was to their own interest to use heavy cement, that they now declined to receive any but that above named. They had lately executed a most important work, which was one of the large detached forts in the deep water of Plymouth Sound; and from using only the highly manufactured cement, they had lost but three blocks during the whole time of the contract. He considered the requirements of the French Engineers were below the standard of what Portland cement should be; but they used it in a peculiar way. They mixed Portland cement with Medina cement, which was much quicker in setting than the Portland, and the union of the two materials might possibly result more satisfactorily when their rates of setting were more nearly alike. It had been asked, What was the use of having a cementing material of greater strength, than the materials which were to be joined together? To that inquiry the general answer might be given that there was no use; but at the same time it did not follow that such a result would attend the use of heavy instead of light cements. The strength of cement might be reduced to any extent that was desired, and economically so, by increasing the proportions of sand employed; and, as for a long time past the price of heavy and light cements in the market had been much the same, there was a considerable saving in using the heavy cement with the larger proportion of sand that it would take. At the same time, it must be admitted, that greater weight meant nothing less than higher manufacture, and that heavy cement was worth a higher price. The natural conclusion was, that the light cement, from the great demand for it, was commanding a higher price than it deserved. The difficulty with Portland cement now was, that it could not be depended upon. If a sudden break in a sea wall occurred, Medina cement could be used, with the certainty of good results; but with Portland cement, it was almost a matter of necessity that it should undergo a course of tedious tests before assurance could be obtained that the cement would not 'blow' in the work, and this bar to its use would remain, until the makers adopted the course pursued in other manufactures, which was, to aim at every possible improvement in quality, with the certainty of a good article, always commanding its value in the market.

Sir CHARLES HARTLEY said, in connection with the employment of cement and pozzolana abroad, that he could give a brief account of certain works he had inspected during the last month on the French and on the Italian coasts. Harbours of refuge were being constructed at Biarritz and at St. Jean de Luz, situated on the rocky seaboard between the mouths of the Adour and the Bidassoa, and consequently at the very head of the Bay of Biscay, a position peculiarly exposed to the fury of Atlantic gales from the N.W. The rise and fall of the tide at this part of the coast varied from 3 mètres to 5 mètres. At Biarritz, the works were carried on under great difficulties, owing to its being without a safe haven for the shelter of small craft, to the number of detached rocks, to the great depth of the sea close in-shore, and to the presence of an almost incessant ground swell even at times of perfect calm. This unfavourable condition of things obliged M. Daguenet, the Engineer in charge, to advance the new jetty from the mainland to its full height at once, by pitching large blocks of béton into the sea from a temporary waggon road. Many of the blocks were broken, and the work often breached, by the adoption of this plan; but such mishaps were difficult to avoid, as there was no possibility of conveying the blocks by water. The blocks used had a cube of 33 tons each, and were composed of Portland cement, stone and sand, in the proportions of 1 part of cement to 2 parts of sand, and 3 parts of broken stones. After being made, they were allowed to remain for three months to harden, and were then conveyed in waggons to the tip-head.

At St. Jean de Luz the proximity of a small tidal harbour rendered the formation of a new jetty[1] a much easier task, for under its shelter blocks were made on the shore, between high water and low water mark, and from one month to two months afterwards, according to the season, were taken to the jetty by a couple of pontoons, and quietly lowered into place. The blocks measured 4 mètres by 2½ mètres and 2 mètres on their sides, and weighed 44 tons. They were begun and completely finished during the ebb of a single tide, and the boards which then encased them, were removed within 24 hours afterwards. The proportions of these blocks were 1 of Portland cement, 2½ of sand, and 3 of stones. They set much sooner, and supported more sand than the Biarritz blocks, in consequence of their frequent immersion in water, immediately after being built: and they were not liable to fracture when deposited, on account of the employment of pontoons. The jetty, above the level of ordinary low water, was entirely constructed of very small rubble—faced with ashlar rarely more than 3 feet cube—set in Roman cement, or rather in the quick-setting Spanish cement, which very nearly resembled it, and which, after being used half an hour, was capable of resisting the heaviest seas. This appeared to be a skilful application of two cements, differing widely in their respective qualities, and however much the durability of a very quick-setting cement might be questioned, its success in the meantime at St. Jean de Luz, where it was employed under trying circumstances, was undoubted.

At Genoa a pier was being carried out in a depth of 42 feet, and was advancing at the rate of 50 mètres annually. Its width at the water-line was about 120 feet; its sea-slope stood at 2 to 1; and its inner slope at 1½ to 1. The body of the work consisted of small rubble and quarry rubbish, the outer coating, next the sea, of natural blocks of limestone from 5 tons to 90 tons in weight, and the inner slope of first and second class rubble. From the water-line to 4 feet below it, the whole width of the pier was covered with a layer of béton built 'in situ,' and the interior quay wall, which had a thickness of 18 feet, and was built of the same material, was founded at a depth of 9 feet, by means of a temporary casing of 3-inch sheet piling, supported by timber walings and stout iron upright bars fixed in the rubble. The béton, thus so extensively used, consisted of 1 part of rich lime, 2 parts of pozzolana, and 3 of broken stones; and so well had it answered, that, along the line of the finished pier, not the slightest sign of settlement could be detected. Above the water line, blocks of 12 mètres cube were built in place, some of them consisting of Italian cement, sand, and shingle, in the proportions of 1, 2, and 3 respectively, and others of mortar, of the same quality and proportions, and third-class rubble.

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[1] This work, like the Biarritz jetty, is intended to have a length of about 300 mètres, founded at an average depth of 24 feet below low-water mark.—C. H.

At Spezzia, pozzolana was used exclusively for the dock walls, where they were set dry, in the proportions of 2 parts of pozzolana to 1 part of lime and 3 parts of stones; but for the quays, built in the water in the manner described by Mr. Hawkshaw, the cement of the country was used in the proportion of 1 part of cement, 2 parts of sand, and 3 parts of broken stone.

At Leghorn, a noble breakwater, 1,040 mètres long, and built in a depth of 30 feet, was on the eve of completion. With the exception of the interior quay wall and the parapet, it consisted entirely of béton blocks, and so well had the blocks, built on shore, been placed by means of pontoons, that the outer, as well as the inner slope, stood immovable, at an angle of 45°. The submerged blocks of 10 mètres cube, consisted of 0·70 of lime, 0·42 of sand, and 0·42 of pozzolana; and the still larger blocks, built in place above water, consisted of third-class rubble, and mortar made of 0·70 of lime and 0·84 of pozzolana.[1]

With regard to the relative value of cement and pozzolana, he might state, that Italian Engineers, as a general rule, preferred the latter, principally on the ground that it had stood the test of centuries, whereas, they contended, that cement for sea works was still on its trial. They argued, moreover, that béton formed of pozzolana was infinitely cheaper in Italy than béton composed of the cements of France, or of England; and, in support of this assertion, they might have quoted the fact, that pozzolana blocks only cost from 20 francs to 28 francs a cubic mètre, at almost any part of the Italian sea-board, whilst a wall built at Genoa, with the Valentine cement of France, had cost 45 francs: the blocks used at Biarritz, and made of Portland cement, 40 francs; and the Cherbourg blocks, made also of Portland, as much as 55 francs per cubic mètre—the cost of materials, labour, and immersion, being included in each case.

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[1] At Leghorn and Spezzia, pozzolana will only be received from a certain locality in the neighbourhood of Rome, where its peculiar colour is unmistakable; and in order to test the actual quantity delivered, it is held that a cubic mètre of this pozzolana weighs 1,195 kilogrammes. On reaching the works, therefore, it is measured and not weighed (so that there may be no temptation to water it), and payment is made at so much per ton—generally 17 francs delivered—by assuming that 10 cubic mètres weigh 12 tons.—C. H.

The choice of a cement, or of pozzolana as a substitute for it, depended so much on the character of the work to be executed, and on its geographical position, that the greatest merit would ever be due to those who selected the materials of construction best adapted to the exigencies of the situation. Thus it might be found, that pozzolana was superior to cement, where, as in Italy, the former was plentiful and cheap, and the latter scarce and dear: that Portland cement was more suitable than pozzolana, wherever there was a constant wash of the sea to contend with, or where, as at Biarritz, great tenacity was required; and that a very quick-setting cement was best where, as at St. Jean de Luz, the construction of a temporary coffer-dam or casing was impossible.

He believed, as a rule, foreign Engineers were bolder in their concrete works, than English Engineers had been hitherto; and he fully agreed with those who predicted a much larger use of English cements, and especially of Portland cement.

Mr. T. D. **Ridley** wished to draw the Author's attention to the mode of applying the tests. At the Thames Embankment Works, when a barge load of cement arrived, an officer appointed by the Board of Works inspected it, and from each tenth bag a sample was taken, which was made into blocks and then tested. In these tests it was almost invariably found, certainly in more than 90 cases out of 100, that the fracture took place at the junction of the small part of the section with the large, and in a curved form. He therefore inferred that the fracture was due, to a certain extent, to transverse, and not altogether to tensile, strain. If such were the case, it would detract from the correctness of the results arrived at in these experiments, and it might be desirable to devise a means of suspending the block, so that the strain should be entirely tensile. He wished to add his meed of praise for the assiduous care bestowed in the testing of these cements, which had, no doubt, greatly contributed to the improved manufacture of cement.

Mr. **John Grant**, in reply, said, he wished to notice the principal exceptions that had been taken to the tests he had ventured to establish. A formidable list of the objections to a very heavy specific gravity and high quality of cement had been made out, and he had arranged those objections in the following order:—First, loss of quantity produced from a given amount of material. Second, loss of fuel in extra burning. Third, wearing out of the kilns. Fourth, wearing out of the millstones. Fifth, impossibility of getting the whole of the calcined results of the materials of the same quality. Sixth, no increase of price to the manufacturers. Seventh, the dangerous character of this high quality of cement. Eighth, its slow-setting character, under certain circumstances. Ninth, its liability to inferior grinding.

With regard to the first six objections, he thought they might be dismissed as being entirely questions for the manufacturer. He would confine himself, therefore, to the two which were raised in an engineering point of view, and chiefly to the point, that cement of this high specific gravity was dangerous. The best answer he could give was the experience which had been obtained in using between 3 millions and 4 millions of bushels during the last six or seven years in the Main Drainage Works of London. Those works had been seen by a large number of the Members of this Institution; and he felt assured that if those works were critically examined, no proofs of this cement being dangerous could possibly be discovered. Any such instance of the cement being dangerous was utterly unknown to him, either in the works on the south, or on the north side, of the river.

As to specific gravity, a table was exhibited by an eminent manufacturer, of which, after the careful examination it had received, it was unnecessary for him to say more than that as far as regarded the experiments on the cements used on the Main Drainage Works, three out of the four lines composing that table were inaccurate.

Table XXXIX. in the Appendix, showing the tensile strains of cements of different specific gravities at different periods, was a summary of four preceding Tables. From this it would be perceived, that cement weighing 109 lbs. per bushel bore a tensile strain at the end of a week of 767 lbs., at the end of a month, of 886 lbs., and at the end of a year of 1,099 lbs.; cement of 112 lbs. (two lines) bore 558 lbs. and 445 lbs. at the end of a week, 784 lbs. and 680 lbs. at the end of a month, and 1,010 lbs. and 1,075 lbs. at the end of a year; but when it weighed 123 lbs., which was the quality of cement used by Mr. Druce at Dover, a marked difference was visible, as then, at the end of a week, it bore 817 lbs., at the end of a month, 936 lbs.; and at the end of a year, 1,230 lbs., considerably higher than those of any of the lighter cements. But there was still stronger proof, and proof which had the advantage of being taken from the ordinary daily records, made without the slightest view of illustrating this point. In those records, which were kept on every contract under the Metropolitan Board of Works, an entry was made of the weight per bushel of every load of cement brought in. He had taken from one of those records, kept at the Outfall Works at Crossness, the results of 327,000 bushels of cement, used there during two years.

In Table XL. were shown the results of the tensile strain of cement varying from 106lbs., 107lbs., and 108lbs. per bushel up to 130 lbs.; beginning at 106 lbs., with a tensile strain of 472 lbs., and finishing at 130lbs., with a tensile strain of 914 lbs. This Table, as was evident, had not been prepared in any way to illustrate this point, for there were several discrepancies in it, and several results that would seem to be unfavourable to the argument he was maintaining; but he had given it in its integrity, and the main lesson which that Table taught was, that weight, legitimately obtained by burning, meant strength. It was true that there might be weight without strength; it might be got improperly; but he said, in the presence of many large manufacturers of cement, most of whom, he was certain, agreed with him, that weight meant strength.

Only that day additional confirmatory proof had been obtained on this point. On the Embankment Works, on the north side of the river, one maker supplied 1,600 bushels. These were tested by 80 tests: the weight of the cement per bushel was found to be 113 lbs., and the tensile strain, at the end of a week, was 596 lbs. Another maker supplied 1,000 bushels, which were tested by 50 tests, the weight per bushel was 117 lbs., the tensile strain, 655 lbs. In another case 1,500 bushels of cement of 121 lbs. were tested by 75 tests: and the tensile strain was more than 790 lbs. Four of those tests broke between 465 lbs. and 650 lbs.; but 71 out of the 75 tests went to the full extent of the instrument, which was 790 lbs., and the cements were not broken at that strain. He had been asked to explain how he came to adopt these tests. He had been challenged on that point, otherwise he had not intended to refer to it. In 1858-9, when he commenced these experiments, he sent to some of the principal manufacturers for samples. He tested these carefully, and made numerous experiments, and found that the manufacturer who had advanced the objection to specific weight, furnished the heaviest of those samples, which also proved to be the strongest cement of all. When he ascertained that it was intended to put such high tests into the specification as 110 lbs. weight per bushel, and 400 lbs. tensile strain at the end of a week, he objected that 400 lbs. was much too high a test in practice. In reply, that maker's own particular cement was pointed out, which showed a result 40 per cent. higher than was specified. The Author was then told candidly, that he must not take these results and expect to get cement, in any quantity, equal to the sample of cement which had been sent in, as it had been prepared specially for the purpose. In fact no other specimen came within 10 per cent. of that sample, and due allowance had been made for this circumstance, as would be seen by a tensile strength of only 60 per cent. having been fixed upon. The weight of

110 lbs., and tensile strain of 400 lbs., were, after full consideration, maintained.

A remark had been made, to the effect that he had gone too far in insisting upon such high tests; but it would be seen that all due caution had been exercised, when it was considered that those tests had been continued for three years, and that it was only after using nearly a million of bushels, averaging 114 lbs. per bushel, and a breaking weight of 607 lbs., that 2 lbs. were added to the weight per bushel, and 100 lbs. to the tensile strain on the 2¼ square inches sectional area. Experience had fully confirmed the moderation of these requirements. Instead of 110 lbs., the average specific weight of 114 lbs. per bushel had been realised; and instead of 400 lbs. tensile strain, 607 lbs. had been attained, the quantity used on the south of the Thames having been about 1½ million bushels. There had been thus no cause to regret the adoption of so high a standard, either from danger to the works, or from any other cause.

While on the question of tensile strain, it might be as well to refer to a point which had been raised by Mr. Coode as to averages—that there might be a high average, through very great extremes. He was happy to state, in general terms, that the minimum had exceeded the specified standard, the maximum being very large indeed, upwards of 1,000 lbs., at 7 days, and the average 50 per cent. above the original standard. To show how important the specific gravity of Portland cement seemed to the manufacturer, he might cite the following fact:—Mr. William Lee, M.P., who was surety for a contractor who failed, had to carry out the Southern High Level Sewer, and was responsible for the strength and soundness of the work. This work he did very well. Mr. Lee manufactured his own cement, but instead of contenting himself with sending cement of 110 lbs. per bushel, breaking at 400 lbs., which was the requirement, he sent in cement of 120 lbs. to the bushel, and a breaking weight of 680 lbs. tensile strain, being 70 per cent. above proof strength. But there was one point which seemed to have been overlooked by the objector to a very high quality—viz., the interest of the purchaser, who, if a contractor, was responsible for the soundness of the work; or, if an Engineer, was staking his credit and good name on the character of the work executed with the cement. This point was of greater importance than the difference of price between cements of first and of second rate qualities.

It had been suggested that Portland cement might pass those tests of weight per bushel, tensile strain, and even the water test, and yet afterwards prove to be dangerous. Such a result was quite impossible. It might pass the weight per bushel; it might, for a short time, pass the test of tensile strain; but it could not pass the test of water. This brought him to the question of what should be done in cases of emergency, in order to ascertain the character of the cement. In such cases, the tests of specific gravity and tensile strain might be laid aside, and the water test alone be applied. A very short experience would enable any one to ascertain whether a cement was safe, strong or weak. When it was necessary to know the character of cement without loss of time, two pats were made of it. One was put into water, and the other was kept dry. By the colour alone it was obvious, whether there was an undue preponderance of clay. If there was, the cake which was put into water would assume a buff colour. If it had been overchalked, or overburnt to the point of danger, little cracks would be perceptible all round the edge in the wet cake; and if the latter of these indications were found, the cement must be laid aside, and it must be ascertained whether it had merely been supplied too new and hot, or was really so improperly manufactured as to be unfit for use.

A question had been asked as to the relative cost of lias lime mortar of first quality, and Portland cement compo or mortar. First-class mortar, at the Liverpool Docks, had been stated to have cost from 9*s.* per cubic yard to 10*s.* per cubic yard. In Mr. Robertson's Paper on Hydraulic Mortar used at the London Docks,[1] it was stated, that the net cost of the first quality of mortar at the works was 14*s.* 3¾*d.* per yard of one kind, and 12*s.* 9*d.* for another. He had endeavoured to ascertain the cost of Portland cement mortar, or compo, mixed in different proportions. In the proportion of 1 to 1 the cost was about 25*s.* per cubic yard, in the proportion of 2 to 1, 18*s.* 3*d.*, of 3 to 1, 15*s.*, of 4 to 1, 13*s.*, and of 5 to 1, 11*s.* 6*d.* per cubic yard. The sand and cement seemed to lose about one-sixth of their bulk when made into compo, and another sixth in setting —altogether about one-third of the original bulk of the sand and cement. It had also been asked whether the cement could be re-gauged? He did not think it could; and he did not think it desirable that Portland cement should be allowed to stand very long, after being gauged, before it was used, inasmuch as the process of setting, or crystallization, appeared to commence immediately after it was wet. If disturbed, after one hour or two hours, it lost much of its strength. The gauging was always done in moderate quantities with a shovel upon a mortar-board.

Portland cement blocks for facing sea-walls might be made of extra strength and density, by increasing the proportion of cement; and (when not of too large size) by compressing the materials in iron moulds or boxes, and using the smallest quantity of water. Some excellent specimens of artificial stone, made in this way some years ago at East Greenwich, might be seen in front of the Terrace, Lewisham, Kent.

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[1] *Vide* Minutes of Proceedings Inst. C. E., vol. xvii. p. 410.

He would add some tables of experiments, made to illustrate the principal points raised in the discussion (Tables XXXVI. and following tables); and would say generally, with regard to these experiments, about 15,000 in number, that they had been made with all integrity upon the cements used in the works, and made by different manufacturers. He had not compared his results with those of any one else; he had given them exactly as they transpired. If these experiments, made for practical purposes, had not been given to this Institution, they would have been buried in the records of the office, and perhaps never been published. He had started with no theory of his own; he had none to establish: moreover, his own knowledge of the subject, was, at first, very slight. What he had ascertained was by experience from day to day, during a period of seven years. He had previously used Portland cement only on a small scale, and in running water, where it was apt to leave the joints, and he had not persevered with it to the extent he had since. But, having been called on to take part in carrying out the Main Drainage Works, it seemed to him to be of the greatest importance to get cement which could be thoroughly depended upon, in works carried through ground so full of water, that the pumping, in many cases, came to 10 per cent. of the whole cost.

Mr. Fowler, President, said, this was one of the most able and useful Papers that had come before the Institution for a long time. But it occurred to him, as no doubt it had to several others, that this Paper would be still more valuable and useful, if it were supplemented by another on blue lias, and greystone lime mortars, so that comparisons could be made between the results of experiments upon mortars, and the results of the experiments made upon Portland cement; and he hoped that from the Author, or from some other Member, such a Paper would be forthcoming, either in the present or in the next session of the Institution. It was almost impossible to arrive at the true value of such a material as Portland cement, excepting by comparison with other cements, or mortars used by Engineers for the same purposes. He trusted that if the subject was undertaken, it would be with the same care as that bestowed upon the experiments upon Portland cement, and that the experiments would be continued for the same period. If another Paper on mortars could be equally well prepared, and the discussion upon it be equally well sustained, this Institution would have, on that subject, confirmation of the most valuable kind,—valuable, he might say, to experienced members as well as to young members; because he thought there was not a single member, whatever his experience had been, who had not derived some new information and some new knowledge from the present Paper, and the discussion that had taken place upon it.

December 12, 1865.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

The discussion upon the Paper, No. 1,129, "Experiments on the Strength of Cement, &c.," occupied the whole evening, to the exclusion of any other subject.

ANNUAL GENERAL MEETING.

December 19, 1865.

JOHN ROBINSON M'CLEAN, President,
in the Chair.

MESSRS. H. HAYTER, T. M. SMITH, and A. WILLIAMS, were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council.

The list of Members proposed for Council, with the record of the several attendances, was read, and the Ballot was commenced; the ballot papers being sent for examination, at intervals of fifteen minutes, in order to expedite the labours of the Scrutineers.

The Annual Report of the Council, on the proceedings of the Institution during the past year, was read.

Resolved,—That the Report of the Council be received and approved; and that it be referred to the Council, to be printed and circulated with the Minutes of Proceedings, in the usual manner.

Resolved,—That the thanks of the Institution are due, and are presented to Messrs. T. Marr Johnson and F. W. Sheilds, for the readiness with which they undertook the office of Auditors of Accounts, and for the clear statement they have laid before the Meeting; and that Messrs. Sheilds and G. P. Bidder, jun., be requested to undertake the office of Auditors for the ensuing year.

Mr. Johnson returned thanks.

Resolved unanimously,—That the new Council be requested to mature a plan for providing additional accommodation for carrying on the business of the Institution, and to report to a Special General Meeting at the earliest opportunity.

It was moved and seconded,—That in future the attendances of the Members of Council be no longer communicated to the Members.

The following Amendment was then proposed, seconded, and carried,—That the record of the attendances of the President, Vice-Presidents, and other Members of Council in Council, and at the Meetings of the Institution of Civil Engineers, be in future printed on the balloting lists.

The Telford Medals, and the Telford and Manby Premiums in books, which had been awarded, were presented.

Resolved,—That the thanks of the Institution are justly due, and are presented to the Vice-Presidents and other Members of Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Fowler, V.P., and Mr. Scott Russell, V.P., returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. M'Clean, President, for his strenuous efforts in the interests of the Institution, for his extraordinary attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. M'Clean returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Charles Manby, the Honorary Secretary, and to Mr. James Forrest, the Secretary, for their constant zeal and devotion to the interests of the Institution, the ability displayed by them in the execution of their duties, and their attention to the individual wishes of the Members.

Mr. Manby and Mr. Forrest severally returned thanks.

The Ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected to fill the several offices in the Council for the ensuing year:—

President.

JOHN FOWLER.

Vice-Presidents.

Joseph Cubitt.
Charles Hutton Gregory.
Thomas Hawksley.
John Scott Russell, F.R.S.

OTHER MEMBERS OF COUNCIL.

Members.

James Abernethy.
William Henry Barlow, F.R.S.
John Frederic Bateman, F.R.S.
Nathaniel Beardmore.
James Brunlees.
Thomas Elliot Harrison.
George Willoughby Hemans.
John Murray.
George Robert Stephenson.
Charles Vignoles, F.R.S.

Associates.

Joseph Freeman.
John Kelk, M.P.

Resolved,—That the thanks of the Meeting be given to Messrs. H. Hayter, T. M. Smith, and A. Williams, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office; and that the ballot-papers be destroyed.

[ANNUAL REPORT.

ANNUAL REPORT.

SESSION 1865-66.

THE position which the Institution of Civil Engineers has now attained must be satisfactory to all its Members, and eminently so to those few, happily still among us, who many years ago, when young men, laboured earnestly to secure for it a recognized place among the scientific societies of the metropolis. But beyond this it seemed to have been anticipated that a time would arrive, when, as a matter of course, every one in any way connected with the profession would belong to this Institution; and it will be noticed in the Charter of Incorporation, and in the Rules and Regulations based upon that Charter, which have remained almost unaltered since they were first drawn up thirty-eight years ago, that in the estimation of the founders the designation 'Civil Engineer' embraced every branch of engineering except that devoted to the military art. It is well that this should be borne in mind when attempts are made to split up into sections that which should ever be one united body, simply on the ground that the division of labour in our calling, as in others, leads to individual attention being concentrated in particular directions, so that, in some instances, only one or two special departments of the profession may be pursued. There seems to be no reason why, at this time, any limitations should be introduced, or any restrictions be imposed, tacitly or otherwise, which might operate to render less comprehensive and complete, the perfect embodiment of the profession in this Institution, and with that view efforts should be directed to consolidate all branches of the profession under one corporation, and thus to add materially to the power, influence, and importance of the profession at large.

The Papers read during the past Session were:—"On the Decay of Materials in Tropical Climates, and the methods employed for arresting and preventing it," by G. O. Mann, (M. Inst. C.E.); "On the Decay of Materials in Tropical Climates, and the methods employed for arresting and preventing it," by W. J. W. Heath, (Assoc. Inst. C.E.); "Description of the Great Grimsby (Royal) Docks, with a Detailed Account of the Enclosed Land, Entrance Locks, Dock Walls, etc.," by Edward Hele Clark; "The River

Tees, and the works upon it, connected with the Navigation," by Joseph Taylor, (Assoc. Inst. C.E.); "Account of the Docks and Warehouses at Marseilles," by Thomas Hawthorn; "The Chey-Air Bridge, Madras Railway," by Edward Johnston, (M. Inst. C.E.); "Giffard's Injector," by John England, (M. Inst. C.E.); "An Account of the Drainage of Paris," by Henry Burdett Hederstedt, (Assoc. Inst. C.E.); "On the Main Drainage of London, and the Interception of the Sewage from the River Thames," by Joseph William Bazalgette, (M. Inst. C.E.); "On the Festiniog Railway for Passengers, as a 2-feet gauge, with sharp curves, and worked by Locomotive Engines," by Capt. Henry Whatley Tyler, R.E., (Assoc. Inst. C.E.); "On Uniform Stress in Girder Work, illustrated by reference to two bridges recently built," by Callcott Reilly, (Assoc. Inst. C.E.), and "On the Maintenance of Railway Rolling Stock," by Edward Fletcher.

The fact of only so few Papers having been read is a sufficient indication of their intrinsic interest, and of the importance of the discussions arising upon them.

The following Telford Medals, and Telford and Manby Premiums of Books, have been awarded to the Authors of these communications:—

1. A Telford Medal, and a Telford Premium, in Books, to Joseph William Bazalgette, M. Inst. C.E., for his Paper "On the Main Drainage of London, and the Interception of the Sewage from the River Thames."
2. A Telford Medal, and a Telford Premium, in Books, to Callcott Reilly, Assoc. Inst. C.E., for his Paper "On Uniform Stress in Girder Work, illustrated by reference to two bridges recently built."
3. A Telford Medal, and a Telford Premium, in Books, to Edward Hele Clark, for his "Description of the Great Grimsby (Royal) Docks, with a Detailed Account of the Enclosed Land, Entrance Locks, Dock Walls, &c."
4. A Telford Medal, and a Telford Premium, in Books, to Capt. Henry Whatley Tyler, R.E., Assoc. Inst. C.E., for his Paper "On the Festiniog Railway for Passengers; as a 2-feet gauge, with sharp curves, and worked by Locomotive Engines."
5. A Telford Premium, in Books, to John England, M. Inst. C.E., for his Paper on "Giffard's Injector."
6. A Telford Premium, in Books, to Thomas Hawthorn, for his "Account of the Docks and Warehouses at Marseilles."
7. A Telford Premium, in Books, to Edward Fletcher, for his Paper "On the Maintenance of Railway Rolling Stock."
8. A Telford Premium, in Books, to Edward Johnston,

M. Inst. C.E., for his Paper on "The Chey-Air Bridge, Madras Railway."

9. A Telford Premium, in Books, to Godfrey Oates Mann, M. Inst. C.E., for his Paper "On the Decay of Materials in Tropical Climates, and the methods employed for arresting and preventing it."
10. A Telford Premium, in Books, to William Jerry Walker Heath, Assoc. Inst. C.E., for his Paper "On the Decay of Materials in Tropical Climates, and the methods employed for arresting and preventing it."
11. A Telford Premium, in Books, to Joseph Taylor, Assoc. Inst. C.E., for his Paper on "The River Tees, and the Works upon it connected with the Navigation."
12. The Manby Premium, in Books, to Henry Burdett Hederstedt, Assoc. Inst. C.E., for his "Account of the Drainage of Paris."

In fulfilment of a promise that, when the works for the Main Drainage of London were sufficiently advanced to fairly test the principles upon which they were based, a description of those works should be given to the Institution, Mr. Bazalgette, during the past session, presented a Paper "On the Main Drainage of London, and the Interception of the Sewage from the River Thames." After glancing at the early history of its sewerage, and alluding to the inquiries instituted by the many Commissions which had dealt with and had reported upon this great question, the Author stated that in the year 1856, when the present Metropolitan Board of Works was formed, he, having been appointed Engineer to the Board, was instructed to prepare a plan, in which the objects to be attained were the interception, as far as practicable by gravitation, of the sewage, together with so much of the rainfall mixed with it as could be reasonably dealt with, so as to divert it from the river in and near London; the substitution of a constant, instead of an intermittent flow in the sewers; the abolition of stagnant and tide-locked sewers, with their consequent accumulations of deposit, and the provision of deep and improved outfalls; and the extension of the sewerage into districts previously, for want of such outfalls, imperfectly drained. The points which required solution, at the threshold of the inquiry, were then successively noticed,—including the determination of the position of the outfalls and the time of discharge, of the quantities of sewage and of rainfall to be carried off, and of the rate of declivity of the sewers. A general description was then given of the course and purpose of the 82 miles of Main Intercepting Sewers, by which the objects sought to be effected had been, or were proposed to be, accomplished; followed by a detailed account of the several works, and of some of the peculiarities and difficulties met with during their construction. It was stated that the total cost of these works would be about £4,100,000, and that they had been nearly completed, with the exception of the Low Level Sewer on the north side of the river, which was intended to drain about one-seventh of the whole area. Some sections of the works had been in operation from two to four years, and the largest portion for more than one year.

This communication was preceded by "An Account of the Drainage of Paris," by Mr. Hederstedt,—the discussion upon the two Papers being taken together,—and from the statements it appeared that, up to the end of the year 1863, there were in operation in Paris 217 miles of drains, or more than four times the length in use up to 1837, and that these drains received only the house and the rain-water, it being remarked that, except in one case, night-soil had no connection whatever with the drains. The minimum inclination of the drains was 1 in 1,000; and as this slope had been found to be insufficient to carry off in suspension the solid materials of the drainage, hand labour, assisted by flushing, had at first been resorted to, for the purpose of cleansing the drains, but now various mechanical contrivances had been introduced, the particulars of which were given in detail.

The careful and elaborate investigation, "On Uniform Stress in Girder Work, illustrated by reference to two bridges recently built," by Mr. Reilly, was suggested by a previous discussion at the Institution. The conclusions sought to be established by the Author were,—that a comparatively small deviation of the centre of stress, upon the section of any bar, of any piece of framework, from the centre of gravity of that section, produced within the limits of elasticity a very great inequality in the distribution of the stress upon that section; that the existence of this unequal distribution of the stress must be detrimental to the strength of any structure in which it existed; that there was no practical or theoretical difficulty in designing a truss, or girder, in which the stress upon every cross section—of all the important members, at all events—should be absolutely uniform; and that the condition of uniform stress was perfectly consistent with the utmost economy of material.

A useful record of an important public work, and an example of what it is in the power of Resident Engineers to contribute to the proceedings of the Institution, were afforded by the "Description of the Great Grimsby (Royal) Docks, with a detailed account of the Enclosed Land, Entrance Locks, Dock Walls, &c.," furnished by Mr. E. H. Clark. These works were designed by the late Mr. Rendel (Past-President Inst. C. E.), and were sanctioned by Parliament in the year 1845. They were advanced into the River Humber for a distance of three-quarters of a mile, and embraced an enclosure of 138 acres of land reclaimed from the river, within which were constructed a dock of 25 acres, with a depth of 6 feet at low water, and of 25 feet 6 inches at high water, and two entrance-locks to the dock, beyond the limits of low water, the larger one being 300 feet in length, by 70 feet in width, and the smaller one 200 feet in length, by 45 feet in width, with a tidal basin of 13 acres, surrounded by timber piers, and having an entrance 200 feet in width. Besides these there were extensive timber ponds, a graving dock, with a width of entrance of 70 feet; a small dock, for fishing craft, 6 acres in extent; and 3,600 feet in length of quays, on which were warehouses of various kinds, and other facilities for carrying on a large trade. All these several works were described in minute detail; and in concluding, the Author referred to the gradual wasting away of the promontory of the Yorkshire coast, opposite to Grimsby, and expressed his belief that, unless immediate steps were taken, a permanent breach would be made between the Spurn Point and the mainland, by which the channel of the River Humber would be diverted from the Lincolnshire coast, and would form a new outlet into the North Sea, when the channel opposite to Grimsby would probably be silted up.

The "Account of the Docks and Warehouses at Marseilles," by Mr. Thomas Hawthorn, was prepared while the Author was acting as one of the Sub-Engineers of the Dock Company there, under M. Barret, the Engineer-in-chief. It also served to show what the younger Members of the profession could do in collecting and arranging the particulars of the works upon which they might happen to be engaged; and when the works were situated in a foreign country, were of the magnitude of those executed and in course of execution at Marseilles, where the imports and exports were estimated to amount to 3,000,000 tons per annum, and were carried out in a manner not usual in England, it became all the more valuable to possess full and accurate details of their construction. In these works five large docks, or basins, were formed by constructing quays or moles, projected into the sea; a pier, or breakwater, parallel to the shore, constituting the seaward side of the enclosure. This pier, or breakwater, was composed of rubble stone, sorted, according to weight, into three classes, the smallest material being used for the core, and the larger pieces being successively added. Artificial blocks of concrete, each of an average weight of 23 tons, were then thrown promiscuously on the outer face of the embankment, to break the force of the sea, and natural blocks of stone were used on the inside of the pier for a quay wall. The composition, the mode of formation, and the cost of the artificial concrete blocks, were given in detail; and it further appeared, that the system adopted in constructing the quay walls of three of the docks, or basins, was somewhat similar to that pursued in forming the inner side of the pier.

A description of the bonded warehouses, which, by the terms of the concession, were required to be of fire-proof materials throughout, was then given. They were six stories in height above the ground-floor, with vaults beneath, and had cost, including the machinery, hydraulic pipes, &c., £500,000. The Paper concluded with the results of some experiments on the hydraulic machinery, for which the designs had been furnished by Sir William Armstrong (M. Inst. C.E.). These experiments were undertaken with a view of ascertaining the working capacity, at different speeds of engine, and the useful mechanical effect of the hydraulic apparatus, as compared with the steam-engine and accumulator.

Captain Tyler's Paper gave the particulars of a highly interesting experiment,—the employment of locomotive engines, for passenger traffic, on the Festiniog Railway, originally a mineral line, 13 miles in length, with a gauge of 2 feet only, having a ruling gradient of 1 in 80, with curves of 2, 3, and 4 chains radius. The engines were stated to be somewhat similar to those which had been found so useful by contractors, and four of them had, up to February, 1865, run 57,000 miles without any accident from leaving the rails. These engines could, at a speed of 10 miles per hour, take up about 50 tons, including the weight of the carriages and trucks, but excluding that of the engine and tender; and they actually conveyed daily, on the up-journey, an average weight of 50 tons of goods, and 100 passengers.

As there was an increasing demand for cheap railways, in districts where it would not be commercially profitable to go to the expense, at the outset, of a first-class railway, it was urged as desirable, that some narrower gauge than 4 feet 8½ inches should be recognized; and it was stated, on the authority of Mr. C. D. Fox, that, in Norway, two short lines were in operation, having a gauge of 3 feet 6 inches, one of which had cost, including rolling stock and stations, £3,000 a mile, and the other, though a more difficult country, £6,000 a mile.

The statistics, comprised in twenty-nine tables, of the Rolling Stock belonging to the North Eastern Railway Company, which formed the subject of Mr. Fletcher's very useful and practical communication "On the Maintenance of Railway Rolling Stock," were arranged to show the total number of the different descriptions of stock, the average age of every class, and the average of the whole, at the end of each year from 1852 to 1864 inclusive. The Tables likewise showed the cost of maintenance of each vehicle per annum, and, in the case of locomotive engines, the cost per mile run. It was submitted that if the average age of all the stock did not exceed one-half the number of years which might be found, by experience, to be a fair average of the existence, or life, of the stock, then that justice was done to the stock in maintenance. It was believed that, making allowances for the improved character of the stock of the present day, and for the large quantity of new stock constantly acquired by all important railways, carriage stock might be fully maintained by an outlay of about 12 per cent. upon its original cost, wagon stock for 6½ per cent., and locomotive stock for 12½ per cent.

Probably, in modern times, a more ingenious and scientific piece of mechanism has not been devised than that known as "Giffard's Injector," for supplying feed-water to the boilers of engines. Mr. England, who submitted a Paper descriptive of this instrument—of the principles of its action, and of its mode of operation—stated that his data were taken from the accounts which had been published in France and in this country respecting it, and that the conditions of working the injector had been kindly furnished by M Turck, of the Western Railway of France. The animated and protracted discussion which ensued upon the reading of this Paper, and the large attendance for several evenings in succession, alike testified to the interest felt in the subject; and the appreciation in which the apparatus is held, may be gathered from the statement made during the course of the discussion, that it had been, or would be, applied to all the locomotive engines belonging to the London and North Western, and almost all the other important lines of railway in Great Britain.

In Mr. Joseph Taylor's "Description of the River Tees, and of the Works upon it connected with the Navigation," it was stated that the effect of the forty-three timber jetties, or groynes, constructed at right angles to the stream, for lengths varying from 40 feet to upwards of 2,000 feet, had been to advance the foreshores to their extremities, by which the width of the original channel had, in many cases, been reduced one-half, and that a large body of tidal water had been thus excluded, reducing the velocity of the ebb tide, and diminishing the scouring force, with a corresponding result in the lower reaches of the river. It was contended that, as a general principle, the operation of dredging, by lowering the bed of the river, and thus increasing the tidal flow, was acting in unison with the natural scouring force; whilst contracting the channel, by jetties, or groynes, shut out a corresponding amount of tidal water, and weakened the scouring force of the ebb tide.

The most important feature in the account of "The Chey-Air Bridge, Madras Railway," by Mr. Edward Johnston, the Resident Engineer, was the method adopted for emptying the water out of the foundation pits. For this purpose the native Piccotah pump, which was much used in many parts of Southern India for irrigation, was employed. It consisted simply of a balance lever, one end of which was variably weighted, by a man walking to and fro upon the lever, while to the other end a bucket was suspended by a long bamboo, another man standing on a staging within the dam, guiding the bucket, and filling it, and emptying it into a wooden trough which surrounded the dam, whence it was discharged by a channel lower down the river. The bucket was made of thin sheet iron, and was capable of containing about five gallons. It was stated that two well-trained men would raise, on an average, about thirty-five gallons per minute, where the lift did not exceed 9 or 10 feet; and at the Chey-Air bridge, at each dam with thirty-six of these pumps, worked by seventy-two coolies, who were relieved every six hours, 1,260 gallons per minute had been raised, the mean lift being from 7 to 8 feet.

Two communications were received on "The Decay of Materials in Tropical Climates, and the methods employed in arresting and preventing it;" one from Mr. Mann, the Resident Engineer and Locomotive Superintendent of the Pernambuco Railway, and the other from Mr. Heath, who had been professionally engaged for a period of seven years on the Ceylon Railway. It was remarkable, that the observations in one Paper were repeated in the other; and that the means of preservation which had been suggested as applicable in Brazil were likewise recommended for Ceylon. With regard to timber, it had been found that when suitable descriptions were properly creosoted, decay was prevented; but it was contended that as the qualities of the different kinds of native woods became better known, as well as the proper time to fell them, and to prepare them by shed-drying, or otherwise, and as a more ready access was obtained to the forests, native woods might ultimately be used with advantage and economy. Ironwork of all kinds should be thoroughly cleansed, be dried by heat, and be payed over with linseed-oil, or coal tar, or be dipped in those materials while hot, before being exported. Bricks, as a rule, were badly burnt, and the clay was imperfectly pugged, so that brickwork, especially in exposed situations, and near to the sea-coast, required to be protected by plastering. With regard to stone, it had been found that the application of linseed-oil not only acted as a preservative, but it rendered soft stones in the course of a short time very hard.

The illustrations for many of these Papers have been engraved, and the letter-press has been corrected, ready for publication, so that there is nothing to prevent these articles being issued at once as pamphlets. Arrangements have been made by which Volumes

XXII., XXIII., XXIV., and XXV., of the Minutes of Proceedings will be in the hands of the Members before the meetings are again resumed.

The information contained in the Minutes of Proceedings, Vols. I. to XX., has been rendered more accessible by the General Index to the series, which was circulated to all the Members early in the present year. It only remains to be added, that those parts of the early volumes of the Minutes of Proceedings of which no copies remained in stock, have been reprinted, and that the whole series, or any portion of it, may be obtained, at cost price, by any Member of the Institution.

Attention is invited to the following paragraph, which was prefixed to the list of Subjects for Premiums, Session 1865-66, issued in the course of the last summer:—

"The Council will be glad to receive, for the purpose of forming an 'Appendix' to the Minutes of Proceedings, the details and results of any Experiments, or Observations, on subjects connected with Engineering Science, or Practice."

It is believed that many Members and Associates of the Institution are in the habit of making experiments, for their guidance in designing and in carrying out the works upon which they may be engaged, and that the results of these experiments are seldom made public, but remain as notes in memorandum-books, which are frequently lost. In the daily practice of the Engineer many isolated facts come to his knowledge, in themselves possibly insufficient to be brought forward in a formal Paper, but which, when put into the shape of notes with illustrative diagrams, and permanently recorded in the manner proposed, could not fail to be very serviceable. The collection of such data might also ultimately enable many useful Papers, both of a scientific and of a practical character, to be compiled. It is, therefore, earnestly requested, that every Member will contribute, to the utmost of his ability, to this part of the annual volume of the Minutes of Proceedings.

Three hundred and ninety separate works have been presented to the Library during the last twelve months,—including, from Mr. Wythes, fifty-three volumes of the "Comptes rendus de l'Académie des Sciences;" from Mr. Bazalgette, twelve large folio volumes of contract drawings, and six volumes of specifications relating to the Main Drainage of London, a gift of peculiar value to all, especially to the junior Members, who should be able to find deposited at the Institution, copies of all similar productions, now generally engraved and printed, and therefore rendered possible at an insignificant cost; and from the Corporation of the Bedford Level, thirty-one tracts relating to the Fens. Endeavours have been made, and are still being made, to obtain for the Library copies of all the reports and treatises that have appeared from time to time on the subject of these drainages. A list of these works, furnished by Mr. Murray, Member of Council, including those in the British Museum, may be consulted at the Institution, and thus it is hoped will soon lead to the completion of the series.

Besides these presents, the Library has been increased by purchases, especially of French and German serials and periodicals; and altogether about three hundred volumes have been added during the year. It is proposed in future to add to the Library a selection of all Blue Books on professional subjects, and the assistance of the Members is asked to render more complete the collection of these publications for previous years. The Catalogue of the Library is now completed, ready for the printer, and in its passage through the press, it will be corrected so as to embrace all works received to the date of publication, which it is hoped may be within the next two months.

The Members will have observed that, during the recess, the collection of portraits of the Past-Presidents of the Institution has been increased by that of the late Sir William Cubitt, by Mr. Boxall, R.A., for which the Institution is indebted to his son, Mr. Joseph Cubitt, V.P., and to whom your special thanks are due.

While on this subject, you will be pleased to learn, that Mr. Boxall, R.A., has accepted a commission to paint a portrait of the late Mr. Joseph Miller (M. Inst. C.E.), so liberal a donor to our funds, and that Mr. Henry Phillips has undertaken to produce a portrait of the late Mr. Robert Stephenson, M.P., Past-President. Difficult as is the task of painting posthumous portraits, the known talents of both these eminent artists lead to the assurance, that the Institution will thus become possessed of two high-class works of art, as well as good likenesses of two Members who during their lifetime sought in every possible way to maintain the reputation of the profession, and at their death bequeathed to us such handsome legacies.

The tabular statement of the transfers, elections, deceases, and resignations of Members of all classes, during the years 1863-64 and 1864-65 (taking into consideration the names which have been erased from the register), appears thus: —

Year.	Honorary Members.	Members.	Associates.	Graduates.	Annual Increase.
1863–64.					
Transferred to Members . .	..	..	13	..	
Elections	..	32	61	..	93 − 38 = 55
Deceases	..	16	9	..	38
Resignations	..	1	4	1	
Erased from the Register . .	..	2	5	..	
1864–65					
Transferred to Members . .	..	..	6	..	
Elections	3	40	99	..	142 - 34 = 108
Deceases	1	9	11	..	34
Resignations	..	2	3	..	
Erased from the Register . .	..	..	8	..	
Members of all Classes on the Books, November 30, 1865 .	20	487	688	8	1,203

Thus showing an increase, during the twelve months, of very nearly 9 per cent. on the total number of Members of all classes at the date of this return.

On the 30th of November, 1860, there were on the books 24 Honorary Members, 355 Members, 537 Associates, and 14 Graduates, making a total of 930 of all classes. Thus, during the past five years, there has been an increase in the number of Members of 132, and of Associates of 151, with a decrease of 4 Honorary Members, and of 6 Graduates, leaving a total effective increase of 273, or of 22½ per cent. of the present number.

It will probably be observed with satisfaction that the class of Members has received numerically almost as large an increase as the class of Associates, and that relatively this increase has been much greater. To the class of Graduates no additions have been made for a period of twenty-four years.

If the Honorary Members and Graduates are omitted from this calculation, the annual increase of Members and Associates stands thus:—

Years.	Members Elected.	Associates Elected.	Total Elected.	Deceases, Resignations, and Erasures.	Effective Increase.
1860	23	39	62	25	37
1861	24	45	69	49	20
1862	35	37	72	15	57
1863	25	49	74	32	42
1864	32	61	93	37	56
1865	40	99	139	33	106

The following Members and Associates, having tendered their resignations, have been permitted to withdraw from the Institution: Arthur Charles Crosse and George Halpin, Members; Edward Wedlake Brayley, Timothy Curley, and Frederick Richard Window, Associates.

The deceases announced during the year have been:—Sir John William Lubbock, Bart., Honorary Member; Col. Frederick Blom, Frederick Braithwaite, John Isaac Hawkins, Capt. Gustaf Lagerheim, John Lewis, James Beaumont Neilson, Jacob Perkins, Frederick Walter Simms, and General Alexander Wilson, Members; George Abernethy, John George Appold, Matthias Wolverley Attwood, William Henry Richards Curll, William Johnson, Edwin Marshall, Benjamin Oliveira, Sir Joseph Paxton, M.P., John Francis Porter, Andrew John Robertson, and Douglas Symonds Sutherland, Associates.

The Memoirs of some of our late friends will be found in an Appendix to this Volume.

By the will of the late Mr. Appold, whose interest in the welfare of the Society was unflagging, provision is made for a sum of One Thousand Pounds being conveyed to the Institution on the decease of Mrs. Appold, and in this case the bequest has not been fettered with any conditions, the intention of our late respected Associate Member being to confer general benefit on a Society to which he was very warmly attached.

The statement of Receipts and Expenditure as prepared by the Auditors, shows that during the year ending the 30th of November last, the receipts from subscriptions and fees alone amounted to £3,950, as against disbursements of all kinds, of £3,511; while the income account was further increased by the dividends upon Trust Funds amounting to £353, and upon other investments not being in trust, of £400, as well as by miscellaneous receipts to the extent of £350. The Council have therefore been again enabled to add to the funded property of the Institution, by the purchase of £1,650 Four per Cent. Debenture Stock in the Great Eastern Railway Company, which they obtained at somewhat less than £90 for each £100 of stock.

Twelve years ago, in the Annual Report for the Session 1853-54, the income of the Institution from all sources was estimated to amount to £1,922. 15*s*. 9*d*., and the expenses, exclusive of the Minutes, to £1,649. During the interval to the present time the receipts from subscriptions and fees have been increased more than twofold, and from dividends and miscellaneous items more than seven times; while on the other hand, the disbursements, excluding also in this case the Minutes, have in the last year been £2,085. 14*s*. 7*d*. only, against the estimated sum of £1,649 at the former period.

The Funds of the Institution now consist of

I. GENERAL FUNDS.

	£.	s.	d.	£.	s.	d.	£.	s.	d.
1. Stephenson Bequest, North Eastern Railway Company's Four per Cent. Debenture Stock				2,000	0	0			
2. Miller Bequest, Reduced Three per Cent. Consols				2,133	6	8			
3. Errington Bequest, Great Northern Railway Company's Four per Cent. Debenture Stock				1,000	0	0			
4. Institution Investments, Great Eastern Railway Company's Four per Cent. Debenture Stock	£3,650								
" " Great Northern ditto	500								
" " London and North Western ditto	1,000								
" " London Brighton and South Coast ditto	1,000			6,150	0	0			
5. Cash in the hands of the Treasurer	£1,248	1	11						
Less Balance of Petty Cash due to the Secretary	21	5	1	1,226	16	10	12,510	3	6

II. BUILDING FUND.

	£.	s.	d.	£.	s.	d.
1. Great Northern Railway Four per Cent. Stock	500	0	0			
2. London and North Western ditto	500	0	0			
3. Great Eastern ditto	1,100	0	0			
4. On Deposit at Union Bank	402	5	5	2,502	5	5

III. TRUST FUNDS.

	£.	s.	d.	£.	s.	d.	£.	s.	d.
1. Telford Fund:—									
Three per Cent. Consols .	2,551	15	10						
Three per Cent. Annuities .	2,342	17	1	4,894	12	11			
Unexpended Dividends, Three per Cent. Consols				1,775	19	8			
2. Manby Donation:—									
Great Eastern Railway Five per Cent. Stock				200	0	0			
3. Miller Fund:—									
Lancashire and Yorkshire Railway Four per Cent. Stock				2,000	0	0			
Great Eastern Railway, Norfolk, Four per Cent. Stock				1,100	0	0	9,970	12	7
Together amounting to							£24,983	1	6

as against £22,541. 5s. 6d. at the date of the last Report.

The amount of arrears of subscriptions for 1865, still remaining due on the 30th of November, is:—

	£.	s.	d.	£.	s.	d.
From members of all classes residing abroad . .	38	6	6			
From members of all classes residing in the United Kingdom	200	0	6	238	7	0
Carried forward				£238	7	0

	£.	s.	d.	£.	s.	d.
Brought forward				238	7	0
The amount of arrears for 1864 is:—						
From members of all classes residing abroad	10	10	0			
From members of all classes residing in the United Kingdom	77	14	0	88	4	0
The amount of arrears for 1863 is:—						
From members of all classes residing abroad	5	5	0			
From members of all classes residing in the United Kingdom	14	14	0	19	19	0
				£346	10	0

In this statement, no notice is taken of the subscriptions which are more than three years in arrear, including the current year. The Council regret to have to report, that they felt compelled, this year, to erase from the register the names of several Associates, some of whose subscriptions were eight and ten years in arrear, and from whom no reply or explanation could be obtained in answer to repeated applications.

The Benevolent Fund, established in connection with the Institution twelve months ago, has since been fully organised, and a Committee of Management has been appointed, who in due course will have to report to the subscribers to the fund, so that this is not the proper occasion to refer to the details of what has been done. It may, however, be stated generally that the donations actually received have amounted to £22,782. 17*s.*, and the Annual Subscriptions for 1865 to £712. 16*s.*, being in the former case a little in excess of, and in the other an increase of 30 per cent. upon, the sums promised respectively.

In preparing the balloting list for the election of the President, Vice-Presidents, and other Members and Associates of Council for the ensuing year, it will have been found that Mr. Fowler is proposed for President.

The vacancy thus caused among the Vice-Presidents has been filled up, by ballot in the Council, by the selection of Mr. Cubitt. With regard to the other members of Council, the names of twelve Members and of four Associates, of whom three of the former and all the latter were not in the previous Council, are submitted in accordance with the rules, although only ten and two respectively can be elected. The number of attendances of the Members of the old Council has been prefixed to each name, in compliance with a resolution passed at the last Annual General Meeting.

A Private Bill, to be submitted to Parliament in the ensuing session, and for which plans, &c., have been deposited and the usual notices have been served, appears calculated to affect very seriously the interests of the Institution. Reference is here made to that part of a project entitled "Houses of Parliament Approaches," which contemplates the compulsory purchase of all the property on the north side of Great George Street, including, of course, the house occupied by the Institution. The Council have felt it to be their duty to direct attention to this subject, believing it to be one which demands mature consideration.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£.	*s.*	*d.*	£.	*s.*	*d.*
To Balance of Petty Cash, Dec. 1, 1864, in the hands of the Secretary	62	3	0			
— Balance in the hands of the Treasurer	1,124	3	2			
				1,186	6	2
— Subscriptions and Fees:—						
Arrears	190	11	6			
Current	3,117	19	6			
Subscriptions for 1866 (in advance)	18	18	0			
Fees	437	17	0			
Life	184	0	0			
				3,949	6	0
— Publication Fund				85	17	0
— Council Fund				45	0	0
— Publications:—Sale of Transactions				207	4	6
— Telford Fund:—						
Dividends, 1 Year, on £2,551. 15*s.* 10*d.*, Three per Cent. Reduced Consols.	75	1	7			
Ditto, 1 Year, on £2,342. 17*s.* 1*d.*, Three per Cent. Reduced Annuities	68	16	4			
Ditto, 1 Year, on £1,775. 19*s.* 8*d.*, Three per Cent. Reduced Annuities	52	0	11			
				195	18	10
— Telford Premiums:—Repayment of Cost of Binding, &c.				25	15	6
— Manby Premium:—						
Dividends, 1 Year, on £200, Great Eastern Railway Company, Five per Cent. Norfolk Preference Stock				9	15	8
— Stephenson Bequest:—						
Dividends, 1 Year, on £2,000, North Eastern Railway Company Four per Cent. Stock				78	3	4
— Miller Fund:—						
Dividends, 1 Year, on £2,000, Lancashire and Yorkshire Railway Company Four per Cent. Stock	78	3	4			
Ditto, 1 Year, on £1,100, Great Eastern Railway Company, Norfolk, Four per Cent. Stock	43	1	5			
				121	4	9
— Miller Bequest:—						
Dividends, 1 Year, on £2,133. 6*s.* 8*d.* Three per Cent. Reduced Annuities				62	13	6
— Errington Bequest.—						
Dividends, 1 Year, on £1,000, Great Northern Railway Company Four per Cent. Stock				39	1	8
— Institution Investments:—						
Dividends, 1 Year, on £2,000, Great Eastern Railway Company, Norfolk, Four per Cent. Stock	78	6	1			
Ditto, ½ year on £1,650, ditto, ditto	32	8	8			
Ditto, 1 year, on £500, Great Northern Railway Company Four per Cent. Stock	19	10	9			
Ditto, on £1,000, London and North Western Railway Company Four per Cent. Stock	39	1	8			
Ditto, on £1,000, London, Brighton, and South Coast Railway Company Four per Cent. Stock	39	1	8			
Interest from Jan. 25 to May 18 on £1,000, on Deposit at the Union Bank of London, Charing Cross Branch	10	14	8			
				219	3	6
— Donations to Library				12	2	0
— Library				0	7	6
— Benevolent Fund				90	12	0
— Building Fund Investment:—						
Dividends, half year, on £1,000, Great Eastern Railway Company Four per Cent. Stock				21	12	4
— Balance of Petty Cash, Dec. 1, 1865, due to the Secretary				21	5	1
				£6,371	9	4

from the 1st DEC., 1864, *to the* 30th NOV., 1865.

PAYMENTS.

Cr.	£.	*s.*	*d.*	£.	*s.*	*d.*
By House, Great George Street:—						
Rent	365	12	6			
Rates and Taxes	45	6	1			
Insurance	19	19	9			
				430	18	4
— Salaries				750	0	0
— Clerks, Messengers, and Housekeeper				258	19	6
— Postage and Parcels:—						
Postage	33	9	7			
Parcels	1	15	9			
				35	5	4
— Stationery, Engraving, Printing Cards, Circulars, &c.				80	17	0
— Coals, Candles, Oil, and Gas:—						
Coals	27	10	0			
Candles	0	1	10			
Oil	1	17	0			
Gas	28	11	11			
				58	0	9
— Tea and Coffee				29	19	3
— Library:—						
Books	72	12	1			
Periodicals	19	6	8			
Map	4	10	0			
Binding Books	49	16	9			
				146	5	6
— Publication, Minutes of Proceedings				1,049	15	0
— Index to Minutes, Vols. I. to XX.				375	11	0
— Telford Premiums				107	18	11
— Watt Medals				5	2	0
— Manby Premium				12	1	8
— Diplomas				27	13	11
— Manuscripts, Original Papers, and Drawings				2	6	11
— Annual Dinner				74	0	0
— Winding and Repairing Clocks				5	3	6
— Incidental Expenses:—						
Christmas Gifts	1	19	0			
Assistance at Meetings	11	0	0			
Beating Carpets and Sweeping Chimneys	2	15	0			
Household Utensils, Repairs, and Expenses	45	8	0			
				61	2	0
— Building Fund				21	12	4
— Benevolent Fund				90	12	0
				3,623	4	11
— Great Eastern Railway Company, £1,650 Four per Cent. Stock				1,500	2	6
— Balance Dec. 1, 1865, in the hands of the Treasurer				1,248	1	11
				£6,371	9	4

Examined and compared the above Account with the Vouchers and the Cash Book, and find this Account to be correct, leaving a Balance in the hands of the Treasurer of Twelve Hundred and Forty-eight Pounds, One Shilling, and Eleven Pence.—Nov. 30th, 1865.

(Signed) T. MARR JOHNSON, } *Auditors.*
FRANCIS W. SHEILDS, }
JAMES FORREST, *Secretary.*

December 7th, 1865.

PREMIUMS AWARDED,

SESSION 1864-65.

THE COUNCIL of the Institution of Civil Engineers have awarded the following Premiums:—

1. A Telford Medal, and a Telford Premium, in Books, to Joseph William Bazalgette, M. Inst. C.E., for his Paper "On the Main Drainage of London, and the Interception of the Sewage from the River Thames."
2. A Telford Medal, and a Telford Premium, in Books, to Callcott Reilly, Assoc. Inst. C.E., for his Paper "On Uniform Stress in Girder Work, illustrated by reference to two bridges recently built."
3. A Telford Medal, and a Telford Premium, in Books, to Edward Hele Clark, for his "Description of the Great Grimsby (Royal) Docks, with a Detailed Account of the Enclosed Land, Entrance Locks, Dock Walls, &c."
4. A Telford Medal, and a Telford Premium, in Books, to Captain Henry Whatley Tyler, R.E., Assoc. Inst. C.E., for his Paper "On the Festiniog Railway for Passengers; as a 2-feet gauge, with sharp curves, and worked by Locomotive Engines."
5. A Telford Premium, in Books, to John England, M. Inst. C.E., for his Paper on "Giffard's Injector."
6. A Telford Premium, in Books, to Thomas Hawthorn, for his "Account of the Docks and Warehouses at Marseilles."
7. A Telford Premium, in Books, to Edward Fletcher, for his Paper "On the Maintenance of Railway Rolling Stock."
8. A Telford Premium, in Books, to Edward Johnston, M. Inst. C.E., for his Paper on "The Chey-Air Bridge, Madras Railway."
9. A Telford Premium, in Books, to Godfrey Oates Mann, M. Inst. C.E., for his Paper "On the Decay of Materials in Tropical Climates, and the Methods employed for arresting and preventing it."
10. A Telford Premium, in Books, to William Jerry Walker Heath, Assoc. Inst. C.E., for his Paper "On the Decay of Materials in Tropical Climates, and the Methods employed for arresting and preventing it."

11. A Telford Premium, in Books, to Joseph Taylor, Assoc. Inst. C.E., for his Paper on "The River Tees, and the Works upon it connected with the Navigation."
12. The Manby Premium, in Books, to Henry Burdett Hederstedt, Assoc. Inst. C.E., for his "Account of the Drainage of Paris."

SUBJECTS FOR PREMIUMS,

Session, 1865-66.

The Council of the Institution of Civil Engineers invite communications on the Subjects comprised in the following list, as well as upon others; such as, 1, Authentic Details of the Progress of any Work in Civil Engineering, as far as absolutely executed (Smeaton's Account of the Edystone Lighthouse may be taken as an example); 2. Descriptions of Engines and Machines of various kinds; or, 3. Practical Essays on Subjects connected with Engineering, as, for instance, Metallurgy. For approved Original Communications, the Council will be prepared to award the Premiums arising out of special funds devoted for the purpose.

The Council will be glad to receive, for the purpose of forming an "Appendix" to the Minutes of Proceedings, the details and results of any Experiments, or Observations, on subjects connected with Engineering Science, or Practice.

1. On the Theory and details of Construction of Metal and Timber Arches.
2. On Land-slips, with the best means of preventing, or arresting them, with examples.
3. On the Principles to be observed in laying out lines of Railway through mountainous countries, with examples of their application in the Alps, the Pyrenees, the Indian Ghauts, the Rocky Mountains of America, and similar cases.
4. On the Principles to be observed in the designing and arrangement of Terminal and other Railway Stations, Repairing Shops, Engine-sheds, &c., with reference to the traffic and the rolling stock.
5. On Railway Ferries, or the Transmission of Railway Trains entire across Rivers, Estuaries, &c.
6. On Locomotive Engines for ascending Steep Inclines, especially when in combination with sharp curves, on Railways.
7. On the Pneumatic System for the conveyance of Passengers and Goods.
8. On the Results of a series of observations on the Flow of Water from the Ground; with accurately-recorded Rain-

Gauge Registries, in the same locality, for a period of not less than twelve months.

9. On the Construction of Catch-water Reservoirs in Mountain Districts, for the supply of Towns, or for manufacturing purposes.
10. Accounts of existing Waterworks; including the source of supply, a description of the different modes of collecting and filtering, the distribution throughout the streets of Towns, and the general practical results.
11. On the Structural Details, and the Results in Use, of Apparatus for the Filtration of large volumes of water.
12. On the construction of Gas-works, the most economical system of distribution of Gas, and the best modes of Illumination in Streets and Buildings.
13. A History of any Fresh Water Channel, Tidal River, or Estuary,—accompanied by plans and longitudinal and cross sections of the same, at various periods, showing the alterations in its condition,—including notices of any works which may have been executed upon it, and of the effects of the works; particularly of the relative value of Tidal and Fresh Water, of the effect of Enclosures from the Tidal Area upon the general regime, of Sluicing where applied to the improvement of the entrance or the removal of a Bar, and of Groynes, or Parallel Training Walls. Also, of Dredging, with a description of the Machinery employed, and the cost of raising and depositing the material.
14. On the Construction of Tidal, or other Dams, in a constant, or variable depth of water; and on the use of wrought iron in their construction.
15. On Graving Docks and mechanical arrangements having a similar object, with the conditions determining their relative applicability in particular cases, as dependent on the rise of tide, the depth of water, and other circumstances.
16. On the Arrangement and Construction of Floating Landing-Stages, for passenger and other traffic, with existing examples.
17. On the different systems of Swing, Lifting, and other opening Bridges, with existing examples.
18. On the Construction of Lighthouses, their Machinery and Lighting Apparatus; with notices of the methods in use for distinguishing the different Lights.
19. On the Measure of Resistance to Steam Vessels at high Velocities.
20. On the Results of the Employment of Steam Power on Canals, and of other measures for the Improvement of Canals as a means of conveyance for heavy traffic.

21. On Turbines and other Water Motors of a similar character, and their construction and performance, in comparison with Water-wheels.
22. On the present systems of Smelting Iron Ores; of the conversion of cast iron into the malleable state, and of the manufacture of iron generally, comprising the distribution and management of Iron-works.
23. On the Manufacture of Iron for Rails and Wheel Tires, having special reference to the increased capability of resisting lamination and abrasion; and accounts of the Machinery required for rolling heavy Rails, Shafts, and bars of Iron of large sectional area.
24. On the Bessemer and other processes of Steel-making; on the present state of the Steel Manufacture on the Continent of Europe; and on the employment of castings in Steel for Railway Wheels and other objects.
25. On the Use of Steel for the Tires and Crankled Axles of Locomotive Engines, especially with reference to its durability and the cost of repairs, as compared with Iron of acknowledged good quality; and on the use of Steel Bars and Plates generally in Engine-work and Machinery, for Boilers and for Shipbuilding, as well as for Bridges.
26. On the safe working strength of Iron and Steel, including the results of experiments on the Elastic Limit of long bars of Iron, and on the rate of decay by rusting, &c., and under prolonged strains.
27. On the Transmission of Electrical Signals through Submarine Cables.
28. On the present relative position of English and Continental Engineering Manufactories, especially with reference to their comparative positions in respect of the cost, and the character of the work produced.
29. Memoirs and Accounts of the Works and Inventions of any of the following Engineers:—Sir Hugh Middleton, Arthur Woolf, Jonathan Hornblower, Richard Trevithick, William Murdoch (of Soho), Alexander Nimmo, and John Rennie.

Original Papers, Reports, or Designs, of these, or other eminent individuals, are particularly valuable for the Library of the Institution.

The Council will not consider themselves bound to award any Premium, should the Communication not be of adequate merit; but they will award more than one Premium, should there be several Communications on the same subject deserving this mark of distinction. It is to be understood that, in awarding the

Premiums, no distinction is made, whether the Communication has been received from a Member, or an Associate of the Institution, or from any other person, whether a Native or a Foreigner.

The Communications must be forwarded, on or before the 1st of January, 1866, to the house of the Institution, No. 25, Great George Street, Westminster, S.W., where copies of this paper, and any further information may be obtained.

CHARLES MANBY, *Honorary Secretary.*
JAMES FORREST, *Secretary.*

25, *Great George Street, Westminster, S. W.,*
July, 1865.

NOTICE.

It has frequently occurred, that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions,—the Council would, therefore, emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers, or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

EXTRACTS FROM THE MINUTES OF COUNCIL, FEB. 23rd, 1835.

'The principal Subjects for which Premiums will be given are:—

"1st. Descriptions, accompanied by Plans and explanatory Drawings, of any work in Civil Engineering, as far as absolutely executed, and which shall contain authentic details of the progress of the work. (Smeaton's Account of the Edystone Lighthouse may be taken as an example.)

"2ndly. Models, or Drawings, with descriptions of useful Engines and Machines; Plans of Harbours, Bridges, Roads, Rivers, Canals, Mines, &c.; Surveys and Sections of Districts of Country.

"3rdly. Practical Essays on subjects connected with Civil Engineering, such as Geology, Mineralogy, Chemistry, Physics, Mechanic Arts, Statistics, Agriculture, &c.; together with Models, Drawings, or Descriptions of any new and useful Apparatus, or Instruments applicable to the purposes of Engineering, or Surveying."

EXCERPT BYE-LAWS, SECTION XIV., CLAUSE 3.

"Every Paper, Map, Plan, Drawing, or Model presented to the Institution shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same, in any way and at any time they may think proper. But should the Council refuse, or delay the publication of such Paper, beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. No person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

INSTRUCTIONS FOR PREPARING COMMUNICATIONS.

The Communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, about thirteen inches by eight inches, the lines being three-quarters of an inch apart, on the one side only, leaving a margin of one inch and a half in width on the left side, in order that the sheets may be bound.

The Drawings should be on mounted paper, and with as many details as may be necessary to illustrate the subject. Enlarged Diagrams, to such a scale that they may be clearly visible, when suspended on the walls of the Theatre of the Institution, at the time of reading the communication, should be sent for the illustration of any particular portions.

Papers which have been read at the Meetings of other Scientific Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

[ORIGINAL

ORIGINAL COMMUNICATIONS,

DRAWINGS, PRESENTS, &c.,

RECEIVED BETWEEN JULY 1st, 1864, AND JUNE 29th, 1865.

ORIGINAL COMMUNICATIONS.

AUTHORS.

Barry, T. D. No. 1,127.—On the Materials and Foundations of Streets in large Towns.

Bazalgette, J. W. No. 1,129.—On the Main Drainage of London, and the Interception of the Sewage from the River Thames.

Bright, Sir C. T. No. 1,135.—The Telegraph to India; and its extension to Australia and China.

Burnell, G. R. No. 1,133.—On the Water Supply of the City of Paris.

England. J. No. 1,128.—Giffard's Injector.

Fernie, J. No. 1,136.—On the Standard Units of Measure of England and France.

Fletcher, E. No. 1,132.—On the Maintenance of Railway Rolling Stock.

Grant, J. No. 1,138—Experiments on the Strength of Cement; chiefly in reference to the Portland Cement used in the Southern Main Drainage Works.

Hawthorn, T. No, 1,121.—Account of the Docks and Warehouses of Marseilles.

Heath, W. J. W. No. 1,125.—On the Decay of Materials in Tropical Climates; and the methods employed for arresting and preventing it.

Hederstedt, H. B.. No. 1,126.—Account of the Drainage of Paris.

Humber, W. No. 1,137.—On the Principles to be observed in the designing and laying out of Terminal and other Railway Stations, Repairing Shops, Engine Sheds, &c., with reference to the Traffic and the Rolling Stock.

Johnston, E. No. 1,123.—The Chey-Air Bridge, Madras Railway.

Preece, W. H. No. 1,134.—On the best means of Communicating between the Passengers, Guards, and Drivers of Trains in motion.

Reilly, C. No. 1,131.—On Uniform Stress in Girder Work; illustrated by reference to two bridges recently built.

Tyler, Capt. H. W., R.E. No. 1,130.—On the Festiniog Railway for Passengers; as a 2-feet gauge, with Sharp Curves, and worked by Locomotive Engines.

CATALOGUE OF PRESENTS.

BOOKS.

DONORS. TITLE OF WORK.

Académie Royale des Sciences, des Lettres, et des Beaux Arts de Belgique. Bulletins de l'Academé 2^{me} série. Tomes XV., XVI., 1863. Tome XVII., 1864. 8vo. Plates and Cuts. Bruxelles, 1863-64.

———— Mémoires de l'Académie, Tome XXXIV. 4to. Plates. Bruxelles, 1864.

———— Mémoires Couronnés et autres Mémoires publiés par l'Académie. Tomes XV., XVI. 8vo. Cuts. Bruxelles, 1863-64.

———— Mémoires Couronnés et Mémoires des Savants Etrangers, publiés par l'Académie. Tome XXXI. 1862-63. 4to. Plate. Bruxelles, 1863.

———— Annuaire de l'Académie. Trentième Année 1864. 12mo. Portrait. Bruxelles, 1864.

Airy, G. B. First Analysis of One Hundred and Seventy-Seven Magnetic Storms, registered by the Magnetic Instruments in the Royal Observatory, Greenwich, from 1841 to 1857. By George Biddell Airy. 4to. London, 1864.

[Excerpt Philosophical Transactions for 1863.]

Akademie der Wissenschaften. Sitzungsberichte, 1864. Band I., II. 8vo. Munchen, 1864-65.

Andrew, W. P. Letter to W. P. Andrew, Esq., Chairman of the Euphrates Valley Railway, on the importance and necessity of the establishment of the Euphrates Valley Route. By Capt. W. B. Selby. Tract. 8vo. London, 1864.

Anonymous. First Report of the Committee of Inquiry on the Ravages of the White Ant. 8vo. St. Helena, 1864.

———— Letter to W. P. Andrew, Esq., on the Importance and Necessity of placing Delhi and Lahore in Raliway Communication with Kurrachee on the Arabian Sea. By an Officer of thirteen years' service in the Punjaub. Tract. 8vo. London, 1865.

———— Portuguese African Territories. Reply to Dr. Livingstone's Accusations and Misrepresentations. By José de Lacerda. Tract. 8vo. London, 1865.

———— The Navies of England, France, America, and Russia. Being an extract from a work on English and French Neutrality, and the Anglo-French Alliance. By

DONORS. TITLE OF WORK.

Rev. C. B. Boynton, D.D. Tract. 8vo. New York, 1865.

Architecten-und Ingenieur-Vereins für das Königreich. Hannover. Zeitschrift. Band X. Jahrgang, 1864. Folios. Plates and Cuts. Hannover, 1864.

———— Die Mittelalterlichen. Bandenkmälen. Folio. Plates and Cuts. Hannover, 1864.

Architectural Publication Society. The Dictionary of Architecture. Part XIV. Folio. Cuts. London, 1864.

Bache, Professor, A.D. Report of the Superintendent of the U.S. Coast Survey, showing the progress of the Survey during the year 1861. 4to. Plates. Washington, 1862.

Barry, T. D. Norwich Board of Health. Report of the City Surveyor, and Mr. F. Sutton, F.C.S., on the State of the River Wensum. Folio. No place, 1864.

Bauerman, H. A Descriptive Catalogue of the Geological, Mining, and Metallurgical Models in the Museum of Practical Geology. By H. Bauerman. 8vo. London, 1865.

Bennoch, F. A Paper on Metropolitan Improvements and Thames Embankment, read at the Society of Arts on Wednesday, April 20, 1857. Tract. 8vo. Plan. London, 1857.

[Excerpt Journal Society of Arts for 1857.]

———— The Bridges of London. "Are more Bridges needed?" Answered affirmatively. Tract. 8vo. Plate. London, 1853.

Birckel, J. J. Historical and Descriptive Sketch of the Mersey Docks and Harbour. 4to. Plates. Liverpool, 1865.

[Reprinted from "The Artizan."]

Blackwell, Mrs. Report upon the Physics and Hydraulics of the Mississippi River; upon the Protection of the Alluvial Region against Overflow, &c. By Captain A. Humphreys and Lieut. H. L. Abbott. 4to. Plates. Philadelphia, 1861.

Boult, S. On the Alleged Submarine Forests on the Shores of Liverpool Bay, and the River Mersey. By J. Boult. Tract. 8vo. Plates. Liverpool, 1865.

[Excerpt Journal Royal Liverpool Polytechnic Society.]

British Association. Report of the Thirty-third Meeting of the British Association for the Advancement of Science, held at Newcastle-upon-Tyne, in August and September, 1863. 8vo. Plates and Cuts. London, 1864.

DONORS. TITLE OF WORK.

British Meteorological Society. Proceedings, Vol. II., Nos. 15-19. Nov., 1863—April, 1864. 8vo. Diagrams and Cuts. London, 1863-64.

Burnell, G. R. Documents relatifs aux Eaux de Paris. 8vo. Map. Paris, 1858-61.

————Horografia ou Gnomonica Portugueza, &c., de A. F. de Fariâ Aragao. 12mo. Lisboa, 1805.

————Les Eaux de Paris; Examen Critique. Par F. de Lasteyrie. 8vo. Paris, 1861.

———— Les Eaux de Paris. Leur Passé, leur Etat Présent, leur Avenir. Par L. Figuier. 8vo. Plate. Paris, 1862.

————Préfet de la Seine. Documents relatifs aux Eaux de Paris. 4to. Paris, 1861.

Canadian Institute. Canadian Journal of Industry, Science, and Art. New Series, Nos. 52-56. June, 1864—Mar. 1865. 8vo. Plates and Cuts. Toronto, 1864-65.

Cautley, Col. Sir P. T. Ganges Canal. A Valedictory Note to Major-General Sir Arthur Cotton, respecting the Ganges Canal. By Col. Sir Proby T. Cautley. Tract. 8vo. London, 1864.

Chadwick, E. Association for the Promotion of Social Science. Address to the Meeting at York, September 26, 1864, on the Effect of Manufacturing Distress on Manufacturing Progress, and on the Improvement of the Condition of the Wage Classes in Agriculture as well as in Manufactures. Tract. 8vo. London, 1864.

———— On the Economical Principles of a Reform of the Legislation and Administration for the Conveyance of Passengers and Goods on Railways. Tract. 8vo. London, 1865.

[Read at a Meeting of the Department of Economy and Trade of the National Association for the Advancement of Social Science, January 31, 1865.]

Challis, Rev. J. Astronomical Observations made at the Observatory of Cambridge. Vol. XX. For the years 1855-60. 4to. Cambridge, 1864.

Chalmers, J. Naval Armour. Tract. 8vo. Plate and Cuts. London, 1865.

Chapman, R. A Treatise on Metallurgy; comprising Mining and general and particular Metallurgical Operations, with a description of Charcoal, Coke, and Anthracite Furnaces, Blast Machines, Hot Blast, Forge Hammers, Rolling Mills, &c. By F. Overman. Fifth edition. 8vo. Cuts. New York, 1864.

DONORS. TITLE OF WORK.

Chapman, R. A Treatise on the Screw Propeller. By J. Bourne. 4to. Plates and Cuts. London, 1852.

——— The Philosophy of Manufactures; or, An Exposition of the Scientific, Moral, and Commercial Economy of the Factory System of Great Britain. By Andrew Ure. Third edition, continued in its details to the present time, by P. L. Simmonds. 8vo. Plate and Cuts. London, 1861.

Chemical Society. Journal. Ser. II., Vol. II. July—Dec., 1864, Jan.—May, 1865. 8vo. London, 1864-65.

Churchill and Son, Messrs. A Manual of Practical Hygiene prepared especially for use in the Medical Department of the Army. By E. A. Parkes, M.D. 8vo. Cuts. London, 1864.

Collinson, Col. Professional Papers, by Officers of the Corps of Royal Engineers. Vol. III., Papers 9-13; Vol. IV., Paper 1; "Lectures" 4, 5. 8vo. Plates and Cuts. Chatham, 1864.

Collyer, Col. The Circular and Standing Orders of the Department of Public Works, from 1833 to the 8th July, 1857; forming a complete Code of Rules for the guidance of Members of the Department on all Matters of Official Routine. 8vo. Plates and Cuts. Madras, 1857.

Daly, C. Révue Générale de l'Architecture et des Travaux Publics. Vol. XXII. 4to. Plates. Paris, 1864-65.

Danvers, J. Report to the Secretary of State for India in Council on Railways in India, for the Years 1863-64, 1864-65. By Juland Danvers. Folio. Maps and Plates. London, 1864-65.

Darley, G. J. A Practical Treatise on the Use of the Microscope, including the Different Methods of preparing and examining Animal, Vegetable, and Mineral Structures. By John Quekett. Third edition. 8vo. Plates and Cuts. London, 1855.

——— Chemical Technology; or, Chemistry in its Applications to the Arts and Manufactures. By Thomas Richardson, Ph. D., and Henry Watts. Second edition. Vol. I. Parts III. and IV. 8vo. Cuts. London 1863-65.

——— Elements of Chemistry; including the Application of the Science in the Arts. By T. Graham. Second edition. 2 vols. 8vo. Cuts. London, 1850.

Denison, Sir W. Roads and Railways in New South Wales and India; with Remarks explanatory of the Advantages likely to result from the employment, under certain circumstances, of Animal Power instead of Steam Power. Tract. 8vo. Madras, 1864.

DONORS. TITLE OF WORK.

Denton, J. B. The Farm Homesteads of England. By J. Bailey Denton. 4to. Plates and Cuts. London, 1864.

——— The Marshes of South Italy; a Few Words bearing upon Land Speculation and Cotton-growing in Italy, Malaria, and Brigandage. Tract. 8vo. London, 1865.

Dixon, J. Traction on Railways, and the Alleged Loss of Power at High Speeds Practically Considered. By John Dixon. Tract. 8vo. Cuts. No place, 1864.

Doyne, W. T. Report upon the Plains and Rivers of Canterbury, New Zealand. By W. T. Doyne. Tract. Folio. Plates. Christchurch, 1864.

Ecole des Mines. Journal et Annales des Mines de France. Sixième série. Tome VI. 8vo. Plates. Paris, 1865.

Falkiner, T. H. Handbook of Specifications; or, Practical Guide to the Architect, Engineer, Surveyor, and Builder, in drawing up Specifications and Contracts for Works and Constructions. Preceded by a Preliminary Essay, Forms of Specifications, Contracts, &c. By T. L. Donaldson. With a Review of the Law of Contracts, and of the Responsibilities of Architects, Engineers, and Builders. By W. C. Glynn. 2 vols. 8vo. Plates and Cuts. London, no date.

——— Practical Specifications of Works executed in Architecture, Civil and Mechanical Engineering, and in Road-making and Sewering. To which are added a Series of practical useful Agreements and Reports. By J. Blenkarn. 8vo. Plates. London, 1865.

——— The English Gentleman's House; or, How to plan English Residences, from the Parsonage to the Palace. With Tables of Accommodation and Cost, and a Series of Selected Plans. By Robert Kerr. Second edition. 8vo. Plates and Cuts. London, 1865.

Folkard, A. The Life, Times, and Scientific Labours of the Second Marquis of Worcester. To which is added a Reprint of his "Century of Inventions," 1863, with a Commentary thereon. By Henry Dircks. 8vo. Plates and Cuts. London, 1865.

Franklin Institute of the State of Pennsylvania. Journal. Third Series, Vols. XLVII.–XLIX. 8vo. Cuts. Philadelphia, 1864-65.

Gale, J. M. The Glasgow Waterworks: Papers read during Session 1863-64 to the Institution of Engineers in Scotland. 8vo. Plates. Glasgow, 1864.

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January 9, 1866.

JOHN FOWLER, President,
in the Chair.

The following Candidates were balloted for and duly elected:—ABRAHAM COATES FITZGIBBON, ALEXANDER GRANT, WILLIAM JACOMB, and FRANCIS CARR MARSHALL, as Members; JOHN CARRUTHERS, Major JOHN UNDERWOOD CHAMPAIN, R.E., EDWARD HELE CLARK, Captain WILLIAM HENRY EDGCOME, R. E., RALPH ELLIOT, JOHN EVANS, MYLES FENTON, ROGERS FIELD, B.A., ALEXANDER M'KERROW, FRANCIS NAPIER, ARTHUR JOHN PEELE, FREDERIC CORNELL REYNOLDS, WILLIAM RHODES, HENRY SCHNEIDER, and HENRY SHIELD, as Associates.

Mr. Fowler addressed the Meeting in the following terms, on taking the Chair for the first time after his election as President:—

GENTLEMEN,

On assuming the chair of this Institution as its President, and undertaking for the first time its duties and responsibilities, allow me to assure you that I feel deeply the honour you have conferred upon me by electing me to this, the highest position to which the Civil Engineer can aspire; and that I feel still more deeply the weight of the duties which are inseparable from this honour. I will also venture earnestly to request you to extend to me your indulgence during my period of office, and afford me your kind co-operation in any efforts I may make for the advancement of our profession, or for increasing the usefulness of this Institution.

I ask this assistance from you with peculiar anxiety, because I cannot but feel that the present is a period of unusual importance to this Society, and that the rapidly increasing prominence of the profession demands at our hands a corresponding care for its efficiency and dignity.

The high degree of material prosperity which this country and its dependencies have now happily enjoyed for a considerable time, has naturally led to great activity in our profession; and probably at no former period have the skill and enterprise of Engineers been so severely taxed as during the last few years; and as civilization continues to advance, and labour to require increased assistance from mechanical contrivances, the connection of Civil Engineering with social progress will become more and more intimate.

I hope I may be allowed to say, however, with a deep feeling of professional pride, that hitherto the inventive genius, the patient perseverance, and the indomitable energy of the members of our profession have not been found unequal to the tasks they have been called upon to perform; and although I have full confidence in the future, I venture to suggest that the present is a fitting moment for considering the means by which our younger brethren may be best prepared for the arduous duties, and growing difficulties, which they will undoubtedly have to encounter in their professional career.

Competition by foreign Engineers.

It is not merely that works of magnitude and novelty are increasing, and will continue to increase, but it is becoming apparent that we shall have to meet the competition of foreign Engineers in many parts of the world; and that great efforts are now being made, not only by careful scholastic education, but by more attention to practice on works, to render the Civil Engineers of France, Germany, and America, formidable rivals to the Engineers of this country.

Here it has always been found that friendly and honourable rivalry among members of the profession has been on the whole beneficial to science and to engineering progress, and we cannot doubt that the same result will follow the more extended rivalry which we shall have now to meet from the Engineers of every nation. At the same time this consideration renders it our especial duty to take care, that the distinguished and leading position which has been so well maintained by our great predecessors, shall not be lowered by those who come after them.

Former Addresses.

My predecessors in this chair have addressed you chiefly upon the interesting topics and works of their own time; and with so large a field demanding their attention, it was natural that they should devote themselves mainly to describe the past and to indicate in outline the features of greatest interest in the present.

My immediate predecessor, Mr. M'Clean, gave to the Institution a description of the remarkable results which had been produced by the general introduction of railways into England in combination with steam power, and clearly pointed out their influence on the increase of its material prosperity and national wealth.

Mr. Hawkshaw pointed out the rapidly increasing importance of wrought iron for engineering works, with the promise of new applications of steel; and the fact and consequences of the increasing speed of railways and steam-boats.

Mr. Bidder, after defining the object and scope of the profession of the Civil Engineer to be "to take up the results discovered by the abstract mathematician, the chemist, and the geologist, and to apply them practically for the commercial advantage of the world at large," illustrated his views by selecting the examples of hydrodynamical science and hydraulic engineering, for the purpose of pointing out the serious mistakes which might result from the neglect of a proper knowledge of true mathematical principles.

Mr. Robert Stephenson described the modern railway system in England up to the period of his address, commenting upon its extent and justly appreciating its value; and he reviewed, in a large and philosophical spirit, its system of management, and the commercial economy which it had produced.

Mr. Locke in like manner selected for his subject a description of the French railway system and its management, in the introduction of which he had himself been so actively engaged.

Another of my predecessors, Sir John Rennie, seems to have been determined that no single topic of professional interest should remain to any future President which he had not himself exhaustively discussed; for he not only presented a complete panorama of all past engineering works, but he gave a descriptive analysis, so full and complete, as to make his Address at once a history of engineers, and a manual of engineering science.

The Future of the Profession.

The whole field of discussion and description of the past has thus been so completely and so ably occupied by my predecessors in this chair, that I shall not attempt to travel over the same ground; but I propose to deal almost exclusively with the future, and endeavour, although I possess no peculiar personal fitness for the task, to suggest some of the means by which the younger members and the rising generation may best prepare themselves for the duties which that future will bring with it.

The Engineering Problems of the Present Time.

I may first briefly notice, for the purpose of illustration and introduction, a few of the great engineering problems of remarkable boldness and novelty which are now presenting themselves for the supply of the future wants and convenience of mankind: amongst them may be enumerated the Suez Canal; the tunnel through, and the railway over, Mont Cenis; railway bridges over and under great rivers and estuaries; new ferry-works of unusual magnitude; vast warehouses and river approaches for commercial cities like Liverpool; railways under, over, and through great cities; long lines of land and ocean telegraphs; and comprehensive schemes of water supply, drainage, and sewerage.

All these works present problems of great interest, and it will require cultivated intelligence, patient investigation, and enlarged experience, to accomplish the task of their satisfactory solution.

For the Suez Canal we must be content to wait a few years before the work be so far advanced as to enable us to judge of the effects of the physical and moral obstacles which to some experienced minds have appeared all but insuperable.

The Mont Cenis Tunnel, and the temporary railway being constructed over its summit, will continue to be watched with interest by all Engineers, and it may yet be a question how far the mode of traction which has been adopted for the temporary railway will prove to be the best. The modified locomotive, with the aid of a central rail, has no doubt succeeded in surmounting gradients which have hitherto been considered to be more severe than is compatible with the economical use of the locomotive engine; but further experience is still required, and the results of the trial will be watched with great interest, because it cannot be doubted that conditions will continue to present themselves to which the ordinary locomotive engine cannot conveniently be applied.

In many of the proposed and future designs of bridges over or under great rivers and estuaries, no novelty in the principles of construction may probably be required; but in other cases the mere magnitude alone will demand new arrangements and combinations, and may possibly also suggest the use of steel, for parts or the whole of the structure.

The docks and warehouses of our great commercial cities are rapidly advancing in importance, and are constantly demanding increased facilities to enable them to meet the exigencies of trade; and for this purpose every possible resource of steam machinery, and hydraulic and pneumatic mechanism, will have to be taxed to obtain convenient and adequate power and expedition.

The new scheme of river approaches at Liverpool is one of the most remarkable proposals of modern times for its boldness in grappling with the difficulties and necessities of a pressing want, and the complete solution of a difficult problem. It is understood that the Engineer of the Mersey Board, who has designed this great work, is preparing a model on a large scale, which I have no doubt will be brought before the Institution.

The railways under, over, and through great cities are amongst the most striking results engendered by the necessities of rapidly increasing and closely crowded population, and may be regarded as one of the most useful economical developments which engineering has supplied to satisfy the requirements of modern civilization. The engineering problems they present are infinite in their number, and interestingly intricate in their character.

Ocean telegraphy is yet in its infancy, but enough has been done by the numerous lines already laid, and by demonstration before this Institution, to prove that further experience alone is wanting

to enable deep or shallow sea cables to be successfully laid and maintained wherever they may be required; and probably in no branch of our profession is the future of greater interest than in the coming telegraphic connection of every part of the world by sea and land, and in the political, commercial, and social results, which must follow such a remarkable increase in the facility of general intercommunication.

The rapid growth of communities to which I have already alluded has also developed the necessity of provision being made for a more abundant supply of pure water, and for a more complete system of sewerage than is now generally possessed by our towns and cities; some of these works are already being carried out, or seriously contemplated, on a scale of almost startling, but not unnecessary, magnitude.

It is plain, therefore, that in every department of civil engineering the wants of commerce and society are pressing more and more urgently upon the resources of our profession. We have ship canals, but the Suez Canal throws them all into the shade. We have long tunnels through our English mountains, but we have now to penetrate the Alps. We have large bridges, but larger are required. We have noble ports, but they are choked with trade, and new accommodation of an improved kind is called for. We have steam ferries across rivers, estuaries, and straits, and rapid ocean steamers, but higher speed and better accommodation are demanded. We have large warehouses with convenient mechanical appliances, but larger warehouses and better mechanical appliances have become a necessity. We have many thousands of miles of telegraphic communication, but nothing short of its universal extension will suffice.

In the solution of these problems, thus rapidly indicated, and in others which could be easily adduced, we may rest perfectly satisfied that the difficulties they present are not to be overcome by a stroke of genius or by a sudden happy thought, but they must be worked out patiently by the combination of true engineering principles, ripe experience, and sound judgment.

DEFINITION OF A CIVIL ENGINEER.

Having thus called your attention to the peculiar position of our profession in consequence of its rapid growth, and pointed out some of the problems which await an early solution, I shall now attempt to describe the nature of the functions of the modern Civil Engineer; and consider how the coming generation can be best prepared for its inevitable work, and to what extent this Institution can be made ancillary to that purpose.

Although we know from history that men have existed from the earliest times who have been distinguished by great mechanical capacity, remarkable skill in working materials, profound science,

and constructive knowledge, yet it is only during the present century that civil engineering can be considered to have become a distinct and recognized profession. Now, however, it has assumed the position of an art of the highest order. Perhaps we may without arrogance be entitled to claim for it the title of a true *science*.

Many attempts have been made to define and describe a Civil Engineer in a few general words, but all such attempts have been more or less unsatisfactory. Still, though it is difficult, if not impossible, to describe an Engineer by a short definition, it is not so difficult to enumerate and describe the nature of the works he is required to design and execute, and the professional duties he is called upon to perform.

CLASSIFICATION OF THE WORKS INTRUSTED TO A CIVIL ENGINEER.

He has to design and prepare drawings, specifications, and estimates, and to superintend the carrying out of works which may be thus enumerated :—

1. Railways, roads, canals, rivers, and all modes of inland communication.
2. Water supply, gas-works, sewerage, and all other works relating to the health and convenience of towns and cities.
3. The reclamation, drainage, and irrigation of large tracts of country.
4. Harbours of refuge and of commerce, docks, piers, and other branches of hydraulic engineering.
5. Works connected with large mines, quarries, ironworks, and other branches of mineral engineering.
6. Works on a large scale connected with steam-engines, with machinery, shipbuilding, and mechanical engineering.

This list, which might be almost indefinitely extended, involves a vast variety of work, and must appear almost appalling to a young Engineer, and yet it greatly concerns his future success that he should, as far as possible, be prepared to undertake any or all of the works embraced in the list.

I believe the personal history of most of us would show that circumstances have led us in a widely different direction in the exercise of our profession, from that which we originally contemplated, and that the success of many men may be distinctly traced to their ability to avail themselves of unforeseen opportunities to advance in some new direction.

Study of objects, and their value.

The Civil Engineer must therefore be prepared for the various classes of constructive works thus enumerated; but in addition to this professional preparation, it is of the first importance as affecting his true position, and the confidence which ought to be reposed in him; that he should also have a correct appreciation of the objects of each work contenmplated, as well as their true value, so that sound advice may be given as to the best means of attaining them; and he must be prepared, if necessary, to advise his employers that the objects which are sought are not commercially worth the cost of the means which would secure them.

It is not the business of an Engineer to build a fine bridge or to construct a magnificent engineering work for the purpose of displaying his professional attainments; but whatever the temptation may be, his duty is to accomplish the end and aim of his employers by such works and such means as are, on the whole, the best and most economically adapted for the purpose.

Choice of materials.

The first question which will present itself to an Engineer with respect to any proposed work, will be the selection of his material; and as this question is so vital to the accomplishment of a satisfactory result, I propose to treat it in a preliminary and special manner. I wish to impress upon every young Engineer a due sense of its importance, because probably a greater number of mistakes have been made by the use of a wrong material, than from any other cause.

Stone.

In the case of stonework, it is essential that the mode of construction shall have reference to the character of the stone; and this requires much of the knowledge of the geologist, the stonemason, and the quarryman, so that the Engineer may know how best to work and set the stone, and what are the peculiarities of the quarry as to its sound or unsound beds; and, in addition, he should have sufficient chemical knowledge to detect any unfitness in the conditions of use to which he proposes to subject the stone.

Let us always bear in mind, in connection with this subject, the example of Sir Christopher Wren, engineer as well as architect, who himself selected the quarries, and sometimes even the blocks of which his structures were composed.

Brick.

Of bricks I must be content with saying, that the power of detecting the good from the bad, the suitable from the unsuitable, must be acquired by the combined assistance of reading, experiment, and practice.

Mortar and cement.

A knowledge of lime, and the art of making the best practicable mortar from each description of building lime, is almost of equal importance to that required for selecting the stone, brick, and building materials themselves, but it is somewhat remarkable, that the art of preparing mortar in a proper manner is not so general as it deserves to be; and to secure good mortar is a matter of continual anxiety to the Engineer.

Mortar for engineering works is ordinarily made from cement (chiefly Portland cement), or from hydraulic lime, such as lias, or from ordinary lime, such as grey or chalk lime.

Cement is chiefly used in combination with sand in various proportions, according to the nature of the work to be executed; and it is not only necessary to possess the requisite knowledge and experience for determining the proper proportions of cement and sand for each individual case, but it is desirable to have the means of determining by direct and repeated experiment the strength and quality of the cement which it is intended to use.

In the case of hydraulic lime, such as lias, the same general knowledge of the proper proportion of sand to be used is also requisite; but, from the great variation in the character of lias lime, and the different proportions of silica and alumina in combination with the lime itself, it is essential to obtain a careful chemical analysis, in order to avoid the great disappointment and bad consequences which may result from ignorance of the various qualities.

Of ordinary limes it is only necessary here to say that they are of almost infinite variety as to quality and constituent parts, and must each be dealt with accordingly; and the Engineer can scarcely take too much trouble to inform himself of the exact nature of each lime he has to use, and the best mode of using it.

Modern science, and the convenient manner in which steam-power can now be applied, have given to the modern Engineer the means of obtaining better mortar from the same materials than was possible before the general introduction of steam.

The heavy rollers and iron pan worked by steam-power are now almost universally used for grinding and mixing lime and sand for works of magnitude: they produce, with properly proportioned ingredients, a mortar so good in quality, and so equal in the time and power of setting, that the Engineer can calculate with certainty upon the conditions under which his designs will be carried out; and when he has become thoroughly acquainted with the quality and power of good mortar, and acquired confidence in its use, he will feel himself justified in its adoption in cases where our predecessors, and even some modern Engineers, would have hardly ventured to employ it in the place of the more costly Portland cement.

Iron

When iron is intended to be used in structures, it is essential to know under what circumstances cast iron is best for the purpose, or when wrought iron should be employed, and also when steel must be resorted to. The profession has probably been assisted to a greater extent by the experiments and writings of its members, and of distinguished men of science in the material of iron, than on any other subject; but these valuable investigations and experiments must be supplemented by the practical knowledge which can only be acquired by attentively studying the peculiarities of material and manufacture.

Cast iron or pig iron remelted and run into moulds is largely used by Engineers for columns and other parts requiring great

power of resisting compressive strains; and as its price per ton is generally about one half of that of wrought iron, it becomes a matter of economic importance to adopt it in all cases where it can be safely and properly used; but it is of the most varied quality and strength, and the greatest attention of the Engineer is required to secure the proper kind.

Wrought iron is perhaps less varied in its quality than cast iron, and for many purposes of engineering it is the safer metal to adopt, from its greater power of resisting tensile strains, and less liability to sudden fracture; but it must be remembered that wrought iron is sometimes pure and of high quality, sometimes very impure and of the commonest quality; and even with the same degree of purity it may be soft and fibrous, or hard and crystalline; therefore it is obvious that the young Engineer should acquire a sound knowledge of its nature both chemically and practically, so as to enable him to obtain the quality he desires, and to know when he has secured it.

It would be easy to enlarge upon this interesting question of wrought iron, but it may suffice to instance armour-plates and rails, as cases where the best quality is required, but the quality, though best, must be different in kind; for armour-plates the iron can scarcely be too soft and fibrous, whilst for rails it can scarcely be too hard and crystalline, provided it is not so brittle as to be liable to fracture by use. Again, in some iron, such as the "best Yorkshire," the quality appears to improve with every additional operation in the manufacture, whilst the ordinary Welsh iron is almost destroyed by repeated manipulation. All these and many other matters connected with iron should therefore be known thoroughly and practically to the Engineer.

In order to illustrate the necessity of the systematic study of the peculiarities of the metals called iron and steel, let me refer to the experiments of Mr. Eaton Hodgkinson, which first demonstrated that the average resistance of cast iron to crushing was more than six times its tenacity, whilst the resistance of wrought iron to crushing was only four-fifths of its tenacity; and it will be remembered that the mathematical investigations he founded upon these experiments first established on a satisfactory and reliable basis the degree and ratio of tensile and crushing force in cast and wrought iron.

With respect to steel, it must be admitted that, before we can safely adopt it to any considerable extent for purposes of construction, it will be necessary to have a similar series of experiments and investigations specially made; but so promising a metal will amply repay all the trouble that may be bestowed upon it. Steel.

Of timber a thorough knowledge should be acquired, as no Timber

material is otherwise more likely to deceive and to disappoint the Engineer. Not only is great difference found in trees of the same general description, such as the numerous varieties of the pine, but the same kind of pine is a different quality of wood in different countries, and even in different soils and climate in the same country; and again the same tree is entirely changed by being "bled," or having its sap withdrawn. The oaks of America, England, and the Continent, are entirely different in their character, and oaks also differ in quality from each other in the same country, and so with numerous other woods used by the Engineer. The strength, durability, and peculiarity of different kinds of timber, and the true value of artificially preserving them, should also be known and understood.

I have selected these examples for the purpose of illustrating this important fact, that before an Engineer can even commence the designs of his works he must have previously obtained a large amount of preliminary information regarding the nature of all the materials employed upon engineering works, so as to enable him to select for his intended structures those materials which will be on the whole the most suitable; having reference to efficiency, durability, and economy.

KNOWLEDGE REQUIRED BY A CIVIL ENGINEER.

I will now proceed to the question of the kind and degree of knowledge which is required to enable a young Engineer to proceed to the actual design of a public work of importance, such as a railway with its stone, brick, and iron structures, its earthworks, and its all-important permanent way, a railway station, a station-roof, docks and their appliances, water-works, breakwaters, or a 'Great Eastern' steam-ship.

Although it has become the practice in modern times for many Civil Engineers to be employed chiefly, or almost entirely, in some one branch of the profession, I desire to repeat my conviction that it is most important that the early preparation and subsequent study should be as extensive as possible, and should embrace every branch of professional practice, not only for the purpose of securing to a young Engineer more numerous opportunities for his advancement, but also because sound knowledge and experience in all branches of engineering will greatly add to his efficiency and value in any special branch, in the same manner that a medical man will be more reliable in his practice on the eye and the ear if he possesses a sound practical and theoretical knowledge of every part of the human frame.

All classes of the profession, but especially the railway, the dock and harbour, and the water-works Engineer, must possess a knowledge of parliamentary proceedings, so as to be able to avoid all

non-compliances with the Standing Orders of Parliament. To do this, it is true, is no easy matter, as the clauses are often drawn up with so little care and practical knowledge that neither engineers nor solicitors, nor the most experienced parliamentary agents, can understand what is intended.

On the subject of parliamentary proceedings generally, it may be taken for granted that all Committees desire to do justice to the cases which are brought before them; and that if they sometimes fail in their decisions, either as regards the interests of the public, or in arranging a fair settlement between antagonistic interests, it is not unfrequently due to the imperfect and crude manner in which cases are presented to them; I would therefore impress on all young Engineers the importance, both to themselves and to their clients, of laying their cases before Committees in the most perfect manner possible, accompanied by full and correct information, carefully prepared and clearly worked out.

Railway engineering.

The professional knowledge required by the railway Engineer commences with surveying of all kinds, the use of the theodolite, the aneroid barometer, the level, the sextant, &c., and includes surveys for preliminary and parliamentary purposes; and also working surveys of minute accuracy, on a large scale, from which engineering works may be set out with precision upon the ground.

The railway Engineer must understand thoroughly the nature of earthwork of every kind, and the proper angles or slopes to be adopted for cuttings and embankments. He must have the requisite qualifications to enable him to design bridges, viaducts, tunnels, and all other incidental works and buildings in the best and most economical manner.

He must have a knowledge of the training of rivers, and of the effect of floods and drainage, in order that he may make accurate provision for the due discharge of water, without waste of money by works unnecessarily large, or to avoid the risk of damage arising from works which are insufficient.

He must be familiar with the various characters of permanent way, the best description of rail, sleeper, fastenings, and ballast, and with the different descriptions of switches, crossings, turntables, signals, and telegraphs.

It is somewhat remarkable that, with all our experience, there should still remain a doubt amongst Engineers as to the best kind of permanent way to be adopted even under similar circumstances. For, although continental Engineers have almost without exception adopted the flat-bottomed or "Vignoles" form of rail, the I form of rail with equal top and bottom webs, and cast-iron chairs and wooden keys, is still largely used in this country.

A collection of facts with respect to the different descriptions of permanent way in use in this and other countries, with a view to a comparison of the advantages and disadvantages of each, would form a most interesting and important Paper for the Institution, especially if it embraced all the recent experiments with reference to the use of steel rails.

The railway Engineer should not be destitute of some knowledge of architecture and such a taste for those graceful outlines and simple appropriate details, which should always characterize the works of an Engineer, avoiding, on the one hand, the unnatural ornamentation which seems to have no connection with the structure, and on the other hand, a disregard of either form, outline, or proportion.

But all such knowledge may fail if there be not a constant supervision and control over the quality of all the materials and the workmanship employed upon the railway; and it is not too much to say that without the practical knowledge, which is obtainable only by having first performed the duties of resident Engineer, it is hopeless to expect that any Engineer can be competent to undertake the responsibility of important works, or be fit to have large sums of money intrusted to him for expenditure. It is in the capacity of resident Engineer that all previous preparation, both scholastic and professional, and all theoretical acquirements, become utilized and rendered of practical value; and it is only after much experience on different works of varied character, dimensions, and materials, that a young student of engineering can claim to take rank as a "Civil Engineer."

Dock and harbour engineering.

The dock and harbour Engineer requires the general and much of the special knowledge of the railway Engineer, such as that which belongs to railways and tramways, and warehouses for goods; and to this he must add a vast amount of other special knowledge not required by the railway Engineer.

For example, he must understand the laws which govern the ebb and flow of the tides, the rise and fall and time of high and low water, and he must have a knowledge of marine surveying, or the best means of ascertaining the set and speed of currents, and their tendency to increase depth of water by scour, or to diminish it by silting; he must also know, in the case of docks, what kind and extent of entrance accommodation to provide, whether the general plan should comprise only a simple lock, or be combined with a half-tide basin; whether single or double gates should be used; and whether it would be necessary to have a tidal basin, or a recessed space, or both.

The nature of the trade to be accommodated in the proposed docks must also be carefully ascertained, in order to provide a proper proportion of quay space and water space, and proper width of quays, warehouses for bonding or for goods to be deposited, sheds for temporary protection, entrance for barges into warehouses from the docks, graving docks and workshops, with mechanical appliances for gates, sluices and pumping, and for shipping or discharging minerals or goods.

He may have to deal with solid foundations, and enjoy a facility of procuring suitable materials for construction, as at Liverpool; or he may have the bad foundations of Hull and other places, where alluvial silt of great depth has accumulated. It may be that good sound stone is too costly for the mass of his work, and that he must resort to brickwork, or rubble stonework, or concrete, or to a combination of all three; but in determining such questions it is impossible that anything but previous experience and habits of careful investigation will enable an Engineer to arrive at the best decision. For it is not enough that his work should be solid, permanent, and safe, but it should be rendered so at the smallest possible cost.

The dock and harbour Engineer is also required to report upon, and to construct, harbours of refuge, piers, landing-stages, lighthouses, forts, canals and their appliances, river improvements, and many other hydraulic works; and, in short, of this branch of engineering it may be truly said that questions are continually arising which require special study and mechanical invention to a greater extent than in almost any other branch of the profession.

Harbours of refuge, being large and costly works, are necessarily few in number, and they are so slow in progress, and have generally been so often changed from their original object and design, that few engineering works have given less satisfaction either to the profession or to the public; but we may hope, that if governments will accurately appreciate the objects they desire to obtain, and boldly grapple with the difficulties and cost of well-matured designs, better and more useful works of this nature may be accomplished than have yet been undertaken.

Water-works and drainage engineering.

The waterworks and drainage Engineer must possess many of the qualifications of the railway and dock Engineer, and especially those which concern earthwork and masonry; he must also be familiar with the means of obtaining information on the subject of rainfall in different localities, the methods of correctly gauging streams of every kind; the proportions of the rainfall available for his purposes after estimating for evaporation and waste, and the extent of the provision to be made for periods of dry weather, or for compensation to mill owners and other interested parties.

He must be conversant with the proper mode of executing the works of reservoirs, conduits, weirs, tunnels, and aqueducts.

He must understand, by the aid of the chemist and his own experience, the nature of the impurities in water, and the best mode of diminishing them, whether mechanically, by subsidence and filtration, or otherwise.

To the waterworks Engineer we must look for the solution of one of the great problems which the rapid increase of population is now forcing upon us; viz., a comprehensive system of conservancy of the flood waters of mountainous localities for the use of large cities and towns, and densely populated districts. We are completely outgrowing our present arrangements for water supply in the great majority of instances; and the convenience, comfort, and health of the public demand that such works when required shall be no longer postponed.

The initiative has been taken as to the question of a new source of water supply for London, in a pamphlet by a well-known authority in this branch of engineering, and sooner or later the subject must command public attention.

The waterworks Engineer must also be competent to design and superintend works of sewerage, as well as of water supply, for large and small towns and localities; and his familiarity with waterworks will naturally aid him in this, as the problems for the discharge and pressure of fluids are identical in both cases.

The great sewerage works of London are now far advanced and have already produced beneficial results; the attention of other still neglected cities and towns has recently been called to this important subject by the loud and startling voice of a threatened return of cholera, and it is to be hoped that the proper authorities will perform their duty promptly and efficiently in this matter; but I cannot here refrain from calling attention to a gigantic evil which has been created by certain drainage and sewerage works already executed, and where the convenience and comfort of one set of people have been secured only by the infliction of a nuisance upon others: I allude to the discharge of collected sewage, without any attempt at purification or deodorisation into streams of pure water.

It is remarkable that an injustice so great, and an evil so intolerable, should in any case have been permitted by Parliament, or by the general law of the land; but now that public attention has been fairly directed to the subject, let us hope that as soon as possible a remedy will be applied to the cases where mischief has already been done, and that care will be taken to prevent its recurrence.

It is no longer a matter of doubt that deodorisation or purification is quite practicable in every locality, and therefore no sewage should ever be permitted to be discharged into existing streams without this purification, or it should be carried out to the sea, and there discharged, as is now proposed for the north side of London.

Mechanical engineering.

The mechanical Engineer deals with the most varied and numerous subjects of all the branches of engineering. They require that he should thoroughly understand the means of producing mechanical power, and of applying it to all the infinite variety of purposes for which it is now demanded. To this end he should be master of the laws of motion and rest, of power and speed, of heat and cold, of liquids and gases.

He must be familiar with the strength of materials under every variety of strain, the proper proportions of parts, and the friction of surfaces.

He must apply existing tools and contrive new ones for his work, and know how to direct power in the raising of weights, or for driving all fixed machinery, or in producing locomotion on land or water.

On railways he is responsible for the vast number of objects required in the machinery for erecting and repairing shops for the engines and carriages, for the pumping and other fixed engines, and especially for the locomotive engine itself, and for rolling and fixed plant generally.

In connection with docks, he is required to design the machinery for opening and closing the dock gates, working sluices, emptying graving docks, or for working the cranes on the quays, or in the sheds and warehouses.

The mechanical Engineer generally also executes the designs of the gas Engineer, even when he does not originate the work which is intrusted to him; and in this branch considerable chemical knowledge must be added to his mechanical qualifications.

For waterworks he designs and executes pumping engines, sluices, valves, stopcocks, &c.

In the case of mines he supplies the designs of the engines for pumping, drawing, winding, or ventilating; for locomotives above and below ground, as well as for the various mechanical appliances required in collieries, mines, and ironworks.

The adoption of the telegraph has been so astonishingly rapid and extensive, both by sea and land, and the purposes to which it has been applied so important, that a considerable body of able and accomplished Engineers have devoted themselves almost exclusively to the subject for the last few years, and have already created a new branch of the profession, called telegraphic engineering; but to be an accomplished telegraph Engineer, it is necessary first to be a good mechanical Engineer and then to add the special knowledge of the electrician, and therefore I include them under the head of mechanical Engineers.

I think it may fairly be traced to the distin that class of mechanical Engineers who have d to telegraphic engineering, that already so muc in telegraphy. Certainly no discussions have sustained in this Institution than those upon this

Allied with the mechanical Engineer is the na only a mechanical Engineer could have construct ships of modern days. The ordinary timber s would have been literally 'at sea' in the cons vessels, wherein the material is iron, and wh vessel requires scientific knowledge of form a strains and of strength, and when steam is t The demand for large and swift vessels for ferries for floating batteries, and for iron-clad sea-goi late been so great that the construction of become a distinct branch of engineering, under architecture.

Mining engineering.

The mining Engineer must possess much of the railway and the mechanical Engineer, and h general knowledge much special knowledge of h know how to sink shafts to the minerals if t extracted from beneath the surface (which is usu how to divert or pump out the water he meets shafts or the workings.

He must know how to excavate and bri minerals, whether they be coal, copper, tin, lead this he must construct subterranean railways, ventilation by fans or furnaces, supply power to mineral to the surface; and when brought the stand the further requisite work, as the coal wil screening, or washing, or manufacturing into will require crushing, washing, or smelting, or operations.

In all these cases and many others, such a surface ironstone and other minerals, by railwa engines, and the working of lifts and inclined Engineer has most important functions to pe machinery to adapt or invent, and relying on skill alone, the investment of large sums development of the mineral wealth of this c made.

Artillery engineering.

I must not altogether omit a passing referen talent which of late years has been devoted weapons of attack and works of defence; and I t claim that it is mainly due to some of the abl Institution that this art has been placed on improved basis, and that as a consequence a new branch of the profession has been actually created—Artillery Engineering.

PREPARATION REQUIRED BY A CIVIL ENGINEER.

Having now enumerated in some detail the various descriptions of work which Engineers are called upon to carry out, I will next proceed to point out the kind of preparation which, in my opinion, is requisite to enable them to perform their work in a proper manner.

I am aware of the difficulty of the task, and of the wide difference of opinion which exists on the subject; but I feel unable to resist the opportunity of bringing this question under the consideration of the Institution, because I feel convinced that at no period in the history of the profession has it been so important as at the present time. Those who may not be disposed to coincide in my views may at least be led by the description of them to throw new light on a subject which is of vital consequence.

We of the passing generation have had to acquire our professional knowledge as we best could, often not until it was wanted for immediate use, generally in haste and precariously, and merely to fulfil the purpose of the hour; and therefore it is that we earnestly desire for the rising generation those better opportunities and that more systematic training for which in our time no provision had been made, because it was not then so imperatively required.

The preparation and training for the Civil Engineer may be shortly described as follows:—

1. General instruction, or a liberal education.
2. Special education as a preparation for technical knowledge.
3. Technical knowledge.
4. Preparation for conducting practical works.

All this preparation and training will have to be acquired at some time or other, and in some order or other, and it is known that in the cases of some successful persons of great perseverance, they have been acquired in a very remarkable order; but at the present time, and with all our modern opportunities, there is no reason why they should not be learned in the most convenient and methodical manner.

I will begin by supposing a boy of fourteen, in whom his parents have discovered a mechanical bias, who has made good progress in his general education, and especially in arithmetic, is of strong constitution, and possessed of considerable energy and perseverance; and unless a boy possesses these tendencies and qualifications it is quite useless to destine him for an Engineer.

Taking the boy of fourteen, however, who possesses the requisite qualifications, and with a determination on his own and his parents' part that he shall be made an Engineer, the period from fourteen it is not only necessary to possess the requisite knowle experience for determining the proper proportions of cem sand for each individual case, but it is desirable to have th of determining by direct and repeated experiment the and quality of the cement which it is intended to use.

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3. Part 1. Technical Vocabulary.
   Part 2. Technical Vocabulary and Dialogues.
4. Earthwork.
5. Limes, Mortars, and Cements.
6. Part 1. Construction of Buildings.
7. Surveying.
8. Roads.
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OFFICERS.—1865-66.

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January 9, 1866.

JOHN FOWLER, President,
in the Chair.

The following Candidates were balloted for and duly elected:—ABRAHAM COATES FITZGIBBON, ALEXANDER GRANT, WILLIAM JACOMB, and FRANCIS CARR MARSHALL, as Members; JOHN CARRUTHERS, Major JOHN UNDERWOOD CHAMPAIN, R.E., EDWARD HELE CLARK, Captain WILLIAM HENRY EDGCOME, R. E., RALPH ELLIOT, JOHN EVANS, MYLES FENTON, ROGERS FIELD, B.A., ALEXANDER M'KERROW, FRANCIS NAPIER, ARTHUR JOHN PEELE, FREDERIC CORNELL REYNOLDS, WILLIAM RHODES, HENRY SCHNEIDER, and HENRY SHIELD, as Associates.

Mr. Fowler addressed the Meeting in the following terms, on taking the Chair for the first time after his election as President:—

GENTLEMEN,

On assuming the chair of this Institution as its President, and undertaking for the first time its duties and responsibilities, allow me to assure you that I feel deeply the honour you have conferred upon me by electing me to this, the highest position to which the Civil Engineer can aspire; and that I feel still more deeply the weight of the duties which are inseparable from this honour. I will also venture earnestly to request you to extend to me your indulgence during my period of office, and afford me your kind co-operation in any efforts I may make for the advancement of our profession, or for increasing the usefulness of this Institution.

I ask this assistance from you with peculiar anxiety, because I cannot but feel that the present is a period of unusual importance to this Society, and that the rapidly increasing prominence of the profession demands at our hands a corresponding care for its efficiency and dignity.

The high degree of material prosperity which this country and its dependencies have now happily enjoyed for a considerable time, has naturally led to great activity in our profession; and probably at no former period have the skill and enterprise of Engineers been so severely taxed as during the last few years; and as civilization continues to advance, and labour to require increased assistance from mechanical contrivances, the connection of Civil Engineering with social progress will become more and more intimate.

I hope I may be allowed to say, however, with a deep feeling of professional pride, that hitherto the inventive genius, the patient perseverance, and the indomitable energy of the members of our profession have not been found unequal to the tasks they have been called upon to perform; and although I have full confidence in the future, I venture to suggest that the present is a fitting moment for considering the means by which our younger brethren may be best prepared for the arduous duties, and growing difficulties, which they will undoubtedly have to encounter in their professional career.

Competition by foreign Engineers.

It is not merely that works of magnitude and novelty are increasing, and will continue to increase, but it is becoming apparent that we shall have to meet the competition of foreign Engineers in many parts of the world; and that great efforts are now being made, not only by careful scholastic education, but by more attention to practice on works, to render the Civil Engineers of France, Germany, and America, formidable rivals to the Engineers of this country.

Here it has always been found that friendly and honourable rivalry among members of the profession has been on the whole beneficial to science and to engineering progress, and we cannot doubt that the same result will follow the more extended rivalry which we shall have now to meet from the Engineers of every nation. At the same time this consideration renders it our especial duty to take care, that the distinguished and leading position which has been so well maintained by our great predecessors, shall not be lowered by those who come after them.

Former Addresses.

My predecessors in this chair have addressed you chiefly upon the interesting topics and works of their own time; and with so large a field demanding their attention, it was natural that they should devote themselves mainly to describe the past and to indicate in outline the features of greatest interest in the present.

My immediate predecessor, Mr. M'Clean, gave to the Institution a description of the remarkable results which had been produced by the general introduction of railways into England in combination with steam power, and clearly pointed out their influence on the increase of its material prosperity and national wealth.

Mr. Hawkshaw pointed out the rapidly increasing importance of wrought iron for engineering works, with the promise of new applications of steel; and the fact and consequences of the increasing speed of railways and steam-boats.

Mr. Bidder, after defining the object and scope of the profession of the Civil Engineer to be "to take up the results discovered by the abstract mathematician, the chemist, and the geologist, and to apply them practically for the commercial advantage of the world at large," illustrated his views by selecting the examples of hydrodynamical science and hydraulic engineering, for the purpose of pointing out the serious mistakes which might result from the neglect of a proper knowledge of true mathematical principles.

Mr. Robert Stephenson described the modern railway system in England up to the period of his address, commenting upon its extent and justly appreciating its value; and he reviewed, in a large and philosophical spirit, its system of management, and the commercial economy which it had produced.

Mr. Locke in like manner selected for his subject a description of the French railway system and its management, in the introduction of which he had himself been so actively engaged.

Another of my predecessors, Sir John Rennie, seems to have been determined that no single topic of professional interest should remain to any future President which he had not himself exhaustively discussed; for he not only presented a complete panorama of all past engineering works, but he gave a descriptive analysis, so full and complete, as to make his Address at once a history of engineers, and a manual of engineering science.

The Future of the Profession.

The whole field of discussion and description of the past has thus been so completely and so ably occupied by my predecessors in this chair, that I shall not attempt to travel over the same ground; but I propose to deal almost exclusively with the future, and endeavour, although I possess no peculiar personal fitness for the task, to suggest some of the means by which the younger members and the rising generation may best prepare themselves for the duties which that future will bring with it.

The Engineering Problems of the Present Time.

I may first briefly notice, for the purpose of illustration and introduction, a few of the great engineering problems of remarkable boldness and novelty which are now presenting themselves for the supply of the future wants and convenience of mankind: amongst them may be enumerated the Suez Canal; the tunnel through, and the railway over, Mont Cenis; railway bridges over and under great rivers and estuaries; new ferry-works of unusual magnitude; vast warehouses and river approaches for commercial cities like Liverpool; railways under, over, and through great cities; long lines of land and ocean telegraphs; and comprehensive schemes of water supply, drainage, and sewerage.

All these works present problems of great interest, and it will require cultivated intelligence, patient investigation, and enlarged experience, to accomplish the task of their satisfactory solution.

For the Suez Canal we must be content to wait a few years before the work be so far advanced as to enable us to judge of the effects of the physical and moral obstacles which to some experienced minds have appeared all but insuperable.

The Mont Cenis Tunnel, and the temporary railway being constructed over its summit, will continue to be watched with interest by all Engineers, and it may yet be a question how far the mode of traction which has been adopted for the temporary railway will prove to be the best. The modified locomotive, with the aid of a central rail, has no doubt succeeded in surmounting gradients which have hitherto been considered to be more severe than is compatible with the economical use of the locomotive engine; but further experience is still required, and the results of the trial will be watched with great interest, because it cannot be doubted that conditions will continue to present themselves to which the ordinary locomotive engine cannot conveniently be applied.

In many of the proposed and future designs of bridges over or under great rivers and estuaries, no novelty in the principles of construction may probably be required; but in other cases the mere magnitude alone will demand new arrangements and combinations, and may possibly also suggest the use of steel, for parts or the whole of the structure.

The docks and warehouses of our great commercial cities are rapidly advancing in importance, and are constantly demanding increased facilities to enable them to meet the exigencies of trade; and for this purpose every possible resource of steam machinery, and hydraulic and pneumatic mechanism, will have to be taxed to obtain convenient and adequate power and expedition.

The new scheme of river approaches at Liverpool is one of the most remarkable proposals of modern times for its boldness in grappling with the difficulties and necessities of a pressing want, and the complete solution of a difficult problem. It is understood that the Engineer of the Mersey Board, who has designed this great work, is preparing a model on a large scale, which I have no doubt will be brought before the Institution.

The railways under, over, and through great cities are amongst the most striking results engendered by the necessities of rapidly increasing and closely crowded population, and may be regarded as one of the most useful economical developments which engineering has supplied to satisfy the requirements of modern civilization. The engineering problems they present are infinite in their number, and interestingly intricate in their character.

Ocean telegraphy is yet in its infancy, but enough has been done by the numerous lines already laid, and by demonstration before this Institution, to prove that further experience alone is wanting

to enable deep or shallow sea cables to be successfully laid and maintained wherever they may be required; and probably in no branch of our profession is the future of greater interest than in the coming telegraphic connection of every part of the world by sea and land, and in the political, commercial, and social results, which must follow such a remarkable increase in the facility of general intercommunication.

The rapid growth of communities to which I have already alluded has also developed the necessity of provision being made for a more abundant supply of pure water, and for a more complete system of sewerage than is now generally possessed by our towns and cities; some of these works are already being carried out, or seriously contemplated, on a scale of almost startling, but not unnecessary, magnitude.

It is plain, therefore, that in every department of civil engineering the wants of commerce and society are pressing more and more urgently upon the resources of our profession. We have ship canals, but the Suez Canal throws them all into the shade. We have long tunnels through our English mountains, but we have now to penetrate the Alps. We have large bridges, but larger are required. We have noble ports, but they are choked with trade, and new accommodation of an improved kind is called for. We have steam ferries across rivers, estuaries, and straits, and rapid ocean steamers, but higher speed and better accommodation are demanded. We have large warehouses with convenient mechanical appliances, but larger warehouses and better mechanical appliances have become a necessity. We have many thousands of miles of telegraphic communication, but nothing short of its universal extension will suffice.

In the solution of these problems, thus rapidly indicated, and in others which could be easily adduced, we may rest perfectly satisfied that the difficulties they present are not to be overcome by a stroke of genius or by a sudden happy thought, but they must be worked out patiently by the combination of true engineering principles, ripe experience, and sound judgment.

DEFINITION OF A CIVIL ENGINEER.

Having thus called your attention to the peculiar position of our profession in consequence of its rapid growth, and pointed out some of the problems which await an early solution, I shall now attempt to describe the nature of the functions of the modern Civil Engineer; and consider how the coming generation can be best prepared for its inevitable work, and to what extent this Institution can be made ancillary to that purpose.

Although we know from history that men have existed from the earliest times who have been distinguished by great mechanical capacity, remarkable skill in working materials, profound science,

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Although we know from history that men have existed from the earliest times who have been distinguished by great mechanical capacity, remarkable skill in working materials, profound science,

and constructive knowledge, yet it is only during the present century that civil engineering can be considered to have become a distinct and recognized profession. Now, however, it has assumed the position of an art of the highest order. Perhaps we may without arrogance be entitled to claim for it the title of a true *science*.

Many attempts have been made to define and describe a Civil Engineer in a few general words, but all such attempts have been more or less unsatisfactory. Still, though it is difficult, if not impossible, to describe an Engineer by a short definition, it is not so difficult to enumerate and describe the nature of the works he is required to design and execute, and the professional duties he is called upon to perform.

CLASSIFICATION OF THE WORKS INTRUSTED TO A CIVIL ENGINEER.

He has to design and prepare drawings, specifications, and estimates, and to superintend the carrying out of works which may be thus enumerated :—

1. Railways, roads, canals, rivers, and all modes of inland communication.
2. Water supply, gas-works, sewerage, and all other works relating to the health and convenience of towns and cities.
3. The reclamation, drainage, and irrigation of large tracts of country.
4. Harbours of refuge and of commerce, docks, piers, and other branches of hydraulic engineering.
5. Works connected with large mines, quarries, ironworks, and other branches of mineral engineering.
6. Works on a large scale connected with steam-engines, with machinery, shipbuilding, and mechanical engineering.

This list, which might be almost indefinitely extended, involves a vast variety of work, and must appear almost appalling to a young Engineer, and yet it greatly concerns his future success that he should, as far as possible, be prepared to undertake any or all of the works embraced in the list.

I believe the personal history of most of us would show that circumstances have led us in a widely different direction in the exercise of our profession, from that which we originally contemplated, and that the success of many men may be distinctly traced to their ability to avail themselves of unforeseen opportunities to advance in some new direction.

Study of objects, and their value.

The Civil Engineer must therefore be prepared for the various classes of constructive works thus enumerated; but in addition to this professional preparation, it is of the first importance as affecting his true position, and the confidence which ought to be reposed in him; that he should also have a correct appreciation of the objects of each work contenmplated, as well as their true value, so that sound advice may be given as to the best means of attaining them; and he must be prepared, if necessary, to advise his employers that the objects which are sought are not commercially worth the cost of the means which would secure them.

It is not the business of an Engineer to build a fine bridge or to construct a magnificent engineering work for the purpose of displaying his professional attainments; but whatever the temptation may be, his duty is to accomplish the end and aim of his employers by such works and such means as are, on the whole, the best and most economically adapted for the purpose.

Choice of materials.

The first question which will present itself to an Engineer with respect to any proposed work, will be the selection of his material; and as this question is so vital to the accomplishment of a satisfactory result, I propose to treat it in a preliminary and special manner. I wish to impress upon every young Engineer a due sense of its importance, because probably a greater number of mistakes have been made by the use of a wrong material, than from any other cause.

Stone.

In the case of stonework, it is essential that the mode of construction shall have reference to the character of the stone; and this requires much of the knowledge of the geologist, the stonemason, and the quarryman, so that the Engineer may know how best to work and set the stone, and what are the peculiarities of the quarry as to its sound or unsound beds; and, in addition, he should have sufficient chemical knowledge to detect any unfitness in the conditions of use to which he proposes to subject the stone.

Let us always bear in mind, in connection with this subject, the example of Sir Christopher Wren, engineer as well as architect, who himself selected the quarries, and sometimes even the blocks of which his structures were composed.

Brick.

Of bricks I must be content with saying, that the power of detecting the good from the bad, the suitable from the unsuitable, must be acquired by the combined assistance of reading, experiment, and practice.

Mortar and cement.

A knowledge of lime, and the art of making the best practicable mortar from each description of building lime, is almost of equal importance to that required for selecting the stone, brick, and building materials themselves, but it is somewhat remarkable, that the art of preparing mortar in a proper manner is not so general as it deserves to be; and to secure good mortar is a matter of continual anxiety to the Engineer.

Mortar for engineering works is ordinarily made from cement (chiefly Portland cement), or from hydraulic lime, such as lias, or from ordinary lime, such as grey or chalk lime.

Cement is chiefly used in combination with sand in various proportions, according to the nature of the work to be executed; and it is not only necessary to possess the requisite knowledge and experience for determining the proper proportions of cement and sand for each individual case, but it is desirable to have the means of determining by direct and repeated experiment the strength and quality of the cement which it is intended to use.

In the case of hydraulic lime, such as lias, the same general knowledge of the proper proportion of sand to be used is also requisite; but, from the great variation in the character of lias lime, and the different proportions of silica and alumina in combination with the lime itself, it is essential to obtain a careful chemical analysis, in order to avoid the great disappointment and bad consequences which may result from ignorance of the various qualities.

Of ordinary limes it is only necessary here to say that they are of almost infinite variety as to quality and constituent parts, and must each be dealt with accordingly; and the Engineer can scarcely take too much trouble to inform himself of the exact nature of each lime he has to use, and the best mode of using it.

Modern science, and the convenient manner in which steam-power can now be applied, have given to the modern Engineer the means of obtaining better mortar from the same materials than was possible before the general introduction of steam.

The heavy rollers and iron pan worked by steam-power are now almost universally used for grinding and mixing lime and sand for works of magnitude: they produce, with properly proportioned ingredients, a mortar so good in quality, and so equal in the time and power of setting, that the Engineer can calculate with certainty upon the conditions under which his designs will be carried out; and when he has become thoroughly acquainted with the quality and power of good mortar, and acquired confidence in its use, he will feel himself justified in its adoption in cases where our predecessors, and even some modern Engineers, would have hardly ventured to employ it in the place of the more costly Portland cement.

Iron

When iron is intended to be used in structures, it is essential to know under what circumstances cast iron is best for the purpose, or when wrought iron should be employed, and also when steel must be resorted to. The profession has probably been assisted to a greater extent by the experiments and writings of its members, and of distinguished men of science in the material of iron, than on any other subject; but these valuable investigations and experiments must be supplemented by the practical knowledge which can only be acquired by attentively studying the peculiarities of material and manufacture.

Cast iron or pig iron remelted and run into moulds is largely used by Engineers for columns and other parts requiring great

power of resisting compressive strains; and as its price per ton is generally about one half of that of wrought iron, it becomes a matter of economic importance to adopt it in all cases where it can be safely and properly used; but it is of the most varied quality and strength, and the greatest attention of the Engineer is required to secure the proper kind.

Wrought iron is perhaps less varied in its quality than cast iron, and for many purposes of engineering it is the safer metal to adopt, from its greater power of resisting tensile strains, and less liability to sudden fracture; but it must be remembered that wrought iron is sometimes pure and of high quality, sometimes very impure and of the commonest quality; and even with the same degree of purity it may be soft and fibrous, or hard and crystalline; therefore it is obvious that the young Engineer should acquire a sound knowledge of its nature both chemically and practically, so as to enable him to obtain the quality he desires, and to know when he has secured it.

It would be easy to enlarge upon this interesting question of wrought iron, but it may suffice to instance armour-plates and rails, as cases where the best quality is required, but the quality, though best, must be different in kind; for armour-plates the iron can scarcely be too soft and fibrous, whilst for rails it can scarcely be too hard and crystalline, provided it is not so brittle as to be liable to fracture by use. Again, in some iron, such as the "best Yorkshire," the quality appears to improve with every additional operation in the manufacture, whilst the ordinary Welsh iron is almost destroyed by repeated manipulation. All these and many other matters connected with iron should therefore be known thoroughly and practically to the Engineer.

In order to illustrate the necessity of the systematic study of the peculiarities of the metals called iron and steel, let me refer to the experiments of Mr. Eaton Hodgkinson, which first demonstrated that the average resistance of cast iron to crushing was more than six times its tenacity, whilst the resistance of wrought iron to crushing was only four-fifths of its tenacity; and it will be remembered that the mathematical investigations he founded upon these experiments first established on a satisfactory and reliable basis the degree and ratio of tensile and crushing force in cast and wrought iron.

Steel.

With respect to steel, it must be admitted that, before we can safely adopt it to any considerable extent for purposes of construction, it will be necessary to have a similar series of experiments and investigations specially made; but so promising a metal will amply repay all the trouble that may be bestowed upon it.

Timber

Of timber a thorough knowledge should be acquired, as no

material is otherwise more likely to deceive and to disappoint the Engineer. Not only is great difference found in trees of the same general description, such as the numerous varieties of the pine, but the same kind of pine is a different quality of wood in different countries, and even in different soils and climate in the same country; and again the same tree is entirely changed by being "bled," or having its sap withdrawn. The oaks of America, England, and the Continent, are entirely different in their character, and oaks also differ in quality from each other in the same country, and so with numerous other woods used by the Engineer. The strength, durability, and peculiarity of different kinds of timber, and the true value of artificially preserving them, should also be known and understood.

I have selected these examples for the purpose of illustrating this important fact, that before an Engineer can even commence the designs of his works he must have previously obtained a large amount of preliminary information regarding the nature of all the materials employed upon engineering works, so as to enable him to select for his intended structures those materials which will be on the whole the most suitable; having reference to efficiency, durability, and economy.

KNOWLEDGE REQUIRED BY A CIVIL ENGINEER.

I will now proceed to the question of the kind and degree of knowledge which is required to enable a young Engineer to proceed to the actual design of a public work of importance, such as a railway with its stone, brick, and iron structures, its earthworks, and its all-important permanent way, a railway station, a station-roof, docks and their appliances, water-works, breakwaters, or a 'Great Eastern' steam-ship.

Although it has become the practice in modern times for many Civil Engineers to be employed chiefly, or almost entirely, in some one branch of the profession, I desire to repeat my conviction that it is most important that the early preparation and subsequent study should be as extensive as possible, and should embrace every branch of professional practice, not only for the purpose of securing to a young Engineer more numerous opportunities for his advancement, but also because sound knowledge and experience in all branches of engineering will greatly add to his efficiency and value in any special branch, in the same manner that a medical man will be more reliable in his practice on the eye and the ear if he possesses a sound practical and theoretical knowledge of every part of the human frame.

All classes of the profession, but especially the railway, the dock and harbour, and the water-works Engineer, must possess a knowledge of parliamentary proceedings, so as to be able to avoid all

non-compliances with the Standing Orders of Parliament. To do this, it is true, is no easy matter, as the clauses are often drawn up with so little care and practical knowledge that neither engineers nor solicitors, nor the most experienced parliamentary agents, can understand what is intended.

On the subject of parliamentary proceedings generally, it may be taken for granted that all Committees desire to do justice to the cases which are brought before them; and that if they sometimes fail in their decisions, either as regards the interests of the public, or in arranging a fair settlement between antagonistic interests, it is not unfrequently due to the imperfect and crude manner in which cases are presented to them; I would therefore impress on all young Engineers the importance, both to themselves and to their clients, of laying their cases before Committees in the most perfect manner possible, accompanied by full and correct information, carefully prepared and clearly worked out.

Railway engineering.

The professional knowledge required by the railway Engineer commences with surveying of all kinds, the use of the theodolite, the aneroid barometer, the level, the sextant, &c., and includes surveys for preliminary and parliamentary purposes; and also working surveys of minute accuracy, on a large scale, from which engineering works may be set out with precision upon the ground.

The railway Engineer must understand thoroughly the nature of earthwork of every kind, and the proper angles or slopes to be adopted for cuttings and embankments. He must have the requisite qualifications to enable him to design bridges, viaducts, tunnels, and all other incidental works and buildings in the best and most economical manner.

He must have a knowledge of the training of rivers, and of the effect of floods and drainage, in order that he may make accurate provision for the due discharge of water, without waste of money by works unnecessarily large, or to avoid the risk of damage arising from works which are insufficient.

He must be familiar with the various characters of permanent way, the best description of rail, sleeper, fastenings, and ballast, and with the different descriptions of switches, crossings, turntables, signals, and telegraphs.

It is somewhat remarkable that, with all our experience, there should still remain a doubt amongst Engineers as to the best kind of permanent way to be adopted even under similar circumstances. For, although continental Engineers have almost without exception adopted the flat-bottomed or "Vignoles" form of rail, the I form of rail with equal top and bottom webs, and cast-iron chairs and wooden keys, is still largely used in this country.

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A collection of facts with respect to the different descriptions of permanent way in use in this and other countries, with a view to a comparison of the advantages and disadvantages of each, would form a most interesting and important Paper for the Institution, especially if it embraced all the recent experiments with reference to the use of steel rails.

The railway Engineer should not be destitute of some knowledge of architecture and such a taste for those graceful outlines and simple appropriate details, which should always characterize the works of an Engineer, avoiding, on the one hand, the unnatural ornamentation which seems to have no connection with the structure, and on the other hand, a disregard of either form, outline, or proportion.

But all such knowledge may fail if there be not a constant supervision and control over the quality of all the materials and the workmanship employed upon the railway; and it is not too much to say that without the practical knowledge, which is obtainable only by having first performed the duties of resident Engineer, it is hopeless to expect that any Engineer can be competent to undertake the responsibility of important works, or be fit to have large sums of money intrusted to him for expenditure. It is in the capacity of resident Engineer that all previous preparation, both scholastic and professional, and all theoretical acquirements, become utilized and rendered of practical value; and it is only after much experience on different works of varied character, dimensions, and materials, that a young student of engineering can claim to take rank as a "Civil Engineer."

Dock and harbour engineering.

The dock and harbour Engineer requires the general and much of the special knowledge of the railway Engineer, such as that which belongs to railways and tramways, and warehouses for goods; and to this he must add a vast amount of other special knowledge not required by the railway Engineer.

For example, he must understand the laws which govern the ebb and flow of the tides, the rise and fall and time of high and low water, and he must have a knowledge of marine surveying, or the best means of ascertaining the set and speed of currents, and their tendency to increase depth of water by scour, or to diminish it by silting; he must also know, in the case of docks, what kind and extent of entrance accommodation to provide, whether the general plan should comprise only a simple lock, or be combined with a half-tide basin; whether single or double gates should be used; and whether it would be necessary to have a tidal basin, or a recessed space, or both.

The nature of the trade to be accommodated in the proposed docks must also be carefully ascertained, in order to provide a proper proportion of quay space and water space, and proper width of quays, warehouses for bonding or for goods to be deposited, sheds for temporary protection, entrance for barges into warehouses from the docks, graving docks and workshops, with mechanical appliances for gates, sluices and pumping, and for shipping or discharging minerals or goods.

He may have to deal with solid foundations, and enjoy a facility of procuring suitable materials for construction, as at Liverpool; or he may have the bad foundations of Hull and other places, where alluvial silt of great depth has accumulated. It may be that good sound stone is too costly for the mass of his work, and that he must resort to brickwork, or rubble stonework, or concrete, or to a combination of all three; but in determining such questions it is impossible that anything but previous experience and habits of careful investigation will enable an Engineer to arrive at the best decision. For it is not enough that his work should be solid, permanent, and safe, but it should be rendered so at the smallest possible cost.

The dock and harbour Engineer is also required to report upon, and to construct, harbours of refuge, piers, landing-stages, lighthouses, forts, canals and their appliances, river improvements, and many other hydraulic works; and, in short, of this branch of engineering it may be truly said that questions are continually arising which require special study and mechanical invention to a greater extent than in almost any other branch of the profession.

Harbours of refuge, being large and costly works, are necessarily few in number, and they are so slow in progress, and have generally been so often changed from their original object and design, that few engineering works have given less satisfaction either to the profession or to the public; but we may hope, that if governments will accurately appreciate the objects they desire to obtain, and boldly grapple with the difficulties and cost of well-matured designs, better and more useful works of this nature may be accomplished than have yet been undertaken.

Water-works and drainage engineering.

The waterworks and drainage Engineer must possess many of the qualifications of the railway and dock Engineer, and especially those which concern earthwork and masonry; he must also be familiar with the means of obtaining information on the subject of rainfall in different localities, the methods of correctly gauging streams of every kind; the proportions of the rainfall available for his purposes after estimating for evaporation and waste, and the extent of the provision to be made for periods of dry weather, or for compensation to mill owners and other interested parties.

He must be conversant with the proper mode of executing the works of reservoirs, conduits, weirs, tunnels, and aqueducts.

He must understand, by the aid of the chemist and his own experience, the nature of the impurities in water, and the best mode of diminishing them, whether mechanically, by subsidence and filtration, or otherwise.

To the waterworks Engineer we must look for the solution of one of the great problems which the rapid increase of population is now forcing upon us; viz., a comprehensive system of conservancy of the flood waters of mountainous localities for the use of large cities and towns, and densely populated districts. We are completely outgrowing our present arrangements for water supply in the great majority of instances; and the convenience, comfort, and health of the public demand that such works when required shall be no longer postponed.

The initiative has been taken as to the question of a new source of water supply for London, in a pamphlet by a well-known authority in this branch of engineering, and sooner or later the subject must command public attention.

The waterworks Engineer must also be competent to design and superintend works of sewerage, as well as of water supply, for large and small towns and localities; and his familiarity with waterworks will naturally aid him in this, as the problems for the discharge and pressure of fluids are identical in both cases.

The great sewerage works of London are now far advanced and have already produced beneficial results; the attention of other still neglected cities and towns has recently been called to this important subject by the loud and startling voice of a threatened return of cholera, and it is to be hoped that the proper authorities will perform their duty promptly and efficiently in this matter; but I cannot here refrain from calling attention to a gigantic evil which has been created by certain drainage and sewerage works already executed, and where the convenience and comfort of one set of people have been secured only by the infliction of a nuisance upon others: I allude to the discharge of collected sewage, without any attempt at purification or deodorisation into streams of pure water.

It is remarkable that an injustice so great, and an evil so intolerable, should in any case have been permitted by Parliament, or by the general law of the land; but now that public attention has been fairly directed to the subject, let us hope that as soon as possible a remedy will be applied to the cases where mischief has already been done, and that care will be taken to prevent its recurrence.

It is no longer a matter of doubt that deodorisation or purification is quite practicable in every locality, and therefore no sewage should ever be permitted to be discharged into existing streams without this purification, or it should be carried out to the sea, and there discharged, as is now proposed for the north side of London.

Mechanical engineering.

The mechanical Engineer deals with the most varied and numerous subjects of all the branches of engineering. They require that he should thoroughly understand the means of producing mechanical power, and of applying it to all the infinite variety of purposes for which it is now demanded. To this end he should be master of the laws of motion and rest, of power and speed, of heat and cold, of liquids and gases.

He must be familiar with the strength of materials under every variety of strain, the proper proportions of parts, and the friction of surfaces.

He must apply existing tools and contrive new ones for his work, and know how to direct power in the raising of weights, or for driving all fixed machinery, or in producing locomotion on land or water.

On railways he is responsible for the vast number of objects required in the machinery for erecting and repairing shops for the engines and carriages, for the pumping and other fixed engines, and especially for the locomotive engine itself, and for rolling and fixed plant generally.

In connection with docks, he is required to design the machinery for opening and closing the dock gates, working sluices, emptying graving docks, or for working the cranes on the quays, or in the sheds and warehouses.

The mechanical Engineer generally also executes the designs of the gas Engineer, even when he does not originate the work which is intrusted to him; and in this branch considerable chemical knowledge must be added to his mechanical qualifications.

For waterworks he designs and executes pumping engines, sluices, valves, stopcocks, &c.

In the case of mines he supplies the designs of the engines for pumping, drawing, winding, or ventilating; for locomotives above and below ground, as well as for the various mechanical appliances required in collieries, mines, and ironworks.

The adoption of the telegraph has been so astonishingly rapid and extensive, both by sea and land, and the purposes to which it has been applied so important, that a considerable body of able and accomplished Engineers have devoted themselves almost exclusively to the subject for the last few years, and have already created a new branch of the profession, called telegraphic engineering; but to be an accomplished telegraph Engineer, it is necessary first to be a good mechanical Engineer and then to add the special knowledge of the electrician, and therefore I include them under the head of mechanical Engineers.

I think it may fairly be traced to the distinguished ability of that class of mechanical Engineers who have devoted themselves to telegraphic engineering, that already so much has been done in telegraphy. Certainly no discussions have been more ably sustained in this Institution than those upon this subject.

Allied with the mechanical Engineer is the naval architect, and only a mechanical Engineer could have constructed the vast steamships of modern days. The ordinary timber ship-builder of old would have been literally 'at sea' in the construction of modern vessels, wherein the material is iron, and when the size of the vessel requires scientific knowledge of form and resistance, of strains and of strength, and when steam is the motive power. The demand for large and swift vessels for ferries, for long voyages, for floating batteries, and for iron-clad sea-going vessels, has of late been so great that the construction of steam vessels has become a distinct branch of engineering, under the name of naval architecture.

Mining engineering.

The mining Engineer must possess much of the knowledge of the railway and the mechanical Engineer, and he must add to that general knowledge much special knowledge of his own. He must know how to sink shafts to the minerals if they require to be extracted from beneath the surface (which is usually the case), and how to divert or pump out the water he meets with either in the shafts or the workings.

He must know how to excavate and bring to the surface minerals, whether they be coal, copper, tin, lead, or iron, and to do this he must construct subterranean railways, provide means of ventilation by fans or furnaces, supply power to lift the extracted mineral to the surface; and when brought there, he must understand the further requisite work, as the coal will probably require screening, or washing, or manufacturing into coke, and the ore will require crushing, washing, or smelting, or possibly all three operations.

In all these cases and many others, such as the collection of surface ironstone and other minerals, by railways and locomotive engines, and the working of lifts and inclined planes, the mining Engineer has most important functions to perform, and special machinery to adapt or invent, and relying on his judgment and skill alone, the investment of large sums of money for the development of the mineral wealth of this country is annually made.

Artillery engineering.

I must not altogether omit a passing reference to the scientific talent which of late years has been devoted to Artillery—its weapons of attack and works of defence; and I think we may fairly claim that it is mainly due to some of the able Members of this Institution that this art has been placed on a new and vastly improved basis, and that as a consequence a new branch of the profession has been actually created—Artillery Engineering.

PREPARATION REQUIRED BY A CIVIL ENGINEER.

Having now enumerated in some detail the various descriptions of work which Engineers are called upon to carry out, I will next proceed to point out the kind of preparation which, in my opinion, is requisite to enable them to perform their work in a proper manner.

I am aware of the difficulty of the task, and of the wide difference of opinion which exists on the subject; but I feel unable to resist the opportunity of bringing this question under the consideration of the Institution, because I feel convinced that at no period in the history of the profession has it been so important as at the present time. Those who may not be disposed to coincide in my views may at least be led by the description of them to throw new light on a subject which is of vital consequence.

We of the passing generation have had to acquire our professional knowledge as we best could, often not until it was wanted for immediate use, generally in haste and precariously, and merely to fulfil the purpose of the hour; and therefore it is that we earnestly desire for the rising generation those better opportunities and that more systematic training for which in our time no provision had been made, because it was not then so imperatively required.

The preparation and training for the Civil Engineer may be shortly described as follows:—

1. General instruction, or a liberal education.
2. Special education as a preparation for technical knowledge.
3. Technical knowledge.
4. Preparation for conducting practical works.

All this preparation and training will have to be acquired at some time or other, and in some order or other, and it is known that in the cases of some successful persons of great perseverance, they have been acquired in a very remarkable order; but at the present time, and with all our modern opportunities, there is no reason why they should not be learned in the most convenient and methodical manner.

I will begin by supposing a boy of fourteen, in whom his parents have discovered a mechanical bias, who has made good progress in his general education, and especially in arithmetic, is of strong constitution, and possessed of considerable energy and perseverance; and unless a boy possesses these tendencies and qualifications it is quite useless to destine him for an Engineer.

Taking the boy of fourteen, however, who possesses the requisite qualifications, and with a determination on his own and his parents' part that he shall be made an Engineer, the period from fourteen to eighteen should be devoted to the special education required by an Engineer, during which mathematics, natural philosophy, land surveying and levelling, drawing, chemistry, mineralogy, geology, strength of materials, mechanical motions, and the principles of hydraulics should be thoroughly mastered.

To accomplish these studies, and, in addition, to make considerable progress in the living languages, French and German especially, it will be necessary to sacrifice to some small extent his classical studies and pure mathematics; and it is, in fact, the partial omission of these studies, and the prominence of those I have enumerated, which constitute a "special education."

If from fourteen to eighteen the boy has made all the progress in these studies which can be reasonably expected from fair abilities and more than average perseverance, the next step is of great importance, and is one respecting which some difference of opinion will exist.

At eighteen a boy, if duly prepared, may either be at once placed in the office of a Civil Engineer for a period of four or five years' pupilage, or he may be placed in a mechanical workshop; or he may be sent to one of our great universities,—and any one of these courses may be the best under particular circumstances, such as local convenience, or as the social position of parents may dictate.

It cannot be doubted that a period of twelve to twenty-four months may be very profitably spent in manufacturing works, before passing into a Civil Engineer's office; but in that case the greatest possible care must be taken that the works selected are adapted in themselves to impart the desired information; and that proper organisation exists for carrying out strict office discipline, regularity of attendance, and due diligence; and that assistance be given systematically to the pupil to enable him to obtain all the advantage possible from his stay at the works.

It is of the greatest importance to the future success of the Engineer that during his professional preparation he should continue his studies of mathematics and scientific works relating to his profession, and also of modern languages.

In the case of its being intended to send the boy to Cambridge or Oxford, it is indispensable that all preliminary professional work, such as a practical knowledge of mechanics, mechanical drawing, surveying and levelling, should be mastered before going to the university, because it can scarcely be expected that he will submit to the drudgery of learning them after his return from a three years' university course, then at the age of, say twenty-two: probably the best plan will be to take him away from his scholastic studies somewhat earlier than eighteen, if it be intended that he should go to the university, and to take especial pains to make him accomplished in the preliminary work of the draughtsman, the surveyor, and the mechanic; so that when he has taken his degree and enters as a pupil in a Civil Engineer's office he will at once commence useful and interesting employment, and will not require more than three years' pupilage.

If arrangements can be so made, and assuming a boy has worked well at school with his general studies, and subsequently with his special studies; and if from the age of seventeen or eighteen he does justice to his opportunities in a good workshop, keeps up his knowledge of the modern languages, proceeds to Cambridge or Oxford, taking a good degree, and afterwards completes his studies as a pupil with a Civil Engineer, probably such a course would constitute the best possible preparation and training which could be obtained; but at the same time it cannot be doubted that it is a somewhat hazardous combination, and can only be successful with great determination on the part of the pupil, to keep his future career always in view, and to prepare for it accordingly, as well before going to the University, during his college career, as after he leaves it.

With respect to the special preparation of young men, between the ages of fourteen and seventeen or eighteen, several of the largest and best proprietary schools and colleges in this country have special classes and departments for the study of the applied sciences; and thence well-prepared pupils are annually sent out to commence their career with engineers, architects, and surveyors; but still the character of this special preparation, in its theoretical branches, is not considered quite equal to that of France or Germany for the Civil Engineer.

It is true that nearly all continental nations have an advantage over this country in the power which the nature of their government gives them of concentrating, in one recognised official school for the preparation of Civil Engineers, all the best available talent of their country.

This plan does not exist in our country, and on the whole we rejoice that it does not; neither does the inducement of Government employment form the chief stimulus to our exertion, for which we are also thankful; but at the same time no good reason can exist why the opportunities of acquiring theoretical preparation in this country should be inferior to those of the Continent: and I have the confident hope, from the anxiety which is now manifested to increase the ranks of our profession, and the desire to have the best possible preparation for it, that even in the theoretical branches we shall shortly have to acknowledge no inferiority to any other nation. In the practical branches we are admittedly superior.

In drawing attention, however, to a comparison between our own to eighteen should be devoted to the special education required by an Engineer, during which mathematics, natural philosophy, land surveying and levelling, drawing, chemistry, mineralogy, geology, strength of materials, mechanical motions, and the principles of hydraulics should be thoroughly mastered.

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In drawing attention, however, to a comparison between our own and other countries, let me be guarded against the possibility of being understood to suggest that this theoretical equality ought to be obtained by any sacrifice whatever of our undoubted great practical knowledge; indeed, on the contrary, I think that the attention to the greater opportunities which young Engineers in this country enjoy, by reason of the number and character of our new public works, than is attainable in other countries, should be constantly encouraged to the utmost possible extent, and that our old superiority as practical Engineers should be ever maintained.

We will now suppose that the general education and the special instruction have been completed, the short probationary pupilage in workshops has been gone through, languages and mathematics kept up and improved, the university course in certain cases completed, and the period has arrived for entering a Civil Engineer's office.

In selecting such office for a pupil, it is important that it should be well organised and not be too large; that the Engineer should be a comparatively young and rising man, and be accustomed to take pupils; but these should be few in number, and bear some proportion to the number and extent of the works in usual course of construction under the Engineer's direction.

It is not necessary to follow the pupil when once the Engineer's office is entered with any detailed advice, because he is no longer a boy, unable to appreciate his position and duty; we assume that he has been highly educated and carefully trained, well knowing that his future success or failure will depend on the degree of diligence with which he avails himself of the opportunities of acquiring knowledge during his pupilage.

The work in the office and in the field should be done to the best of his ability, and after the pupil has become a skilful draughtsman, and is capable of taking out quantities of engineering works, and preparing detailed estimates methodically arranged, he will then probably proceed to work out details of designs, and make calculations of strengths and strains, and thus become of real value in the office, at the same time making substantial progress and rapid improvement for himself.

He should avail himself of every opportunity of mastering the purpose and the principles of construction of the work brought to his notice both in the office and in execution; he should ascertain the cost price of all the materials and workmanship employed, separating the items into every minute detail; and he should continue this practice systematically with all works on which he is engaged.

The information which, amongst much beside, should be obtained during pupilage, and which is necessary to constitute a sound Engineer, is—

1st. A fair knowledge of the most fitting material for any given work, under any given circumstances.

2nd. The power of designing any ordinary work with a maximum of strength and a minimum of material and labour.

3rd. A knowledge of the means of ascertaining the cost price of any ordinary engineering work.

The information or knowledge included in this brief enumeration may be called practical knowledge; and it cannot be too often urged upon young Engineers that theory and practice must always go together, hand in hand, and that they are not only not inconsistent or conflicting, but that they are necessarily united, and must both be fully developed in the same person before he can become a properly qualified "Civil Engineer."

The period of pupilage should be from three to five years, depending on the circumstances which have been previously indicated, and, in addition to his attention to the office, and outdoor works, it will be well, while keeping up his preparatory studies, especially mathematics, that he should improve his acquaintance with the French and German languages, and keep up his knowledge of their engineering literature, and also avail himself professionally and personally of the advantages offered by this Institution.

In the case of the mechanical Engineer, however, it will be seen that although all scholastic and scientific training should be the same as that previously described for all other branches, the period of pupilage of the mechanical Engineer must necessarily be passed chiefly in large workshops or manufacturing establishments.

THE INSTITUTION

I propose now to consider in what manner this Institution can be made available in the preparation of this young Engineer, and more useful to the profession generally, and as a first step allow me, very briefly, to trace its history and refer to its present prosperity.

It will be remembered that The Institution of Civil Engineers was established on January 2, 1818, and Telford was formally installed President on March 21, 1820. The origin of the Institution was very humble. About the year 1816 Mr. Henry Robinson Palmer, who was then articled to Mr. Bryan Donkin, suggested to Mr. Joshua Field the idea of forming a Society of young Engineers for their mutual improvement in mechanical and engineering science. The earliest members were Mr. Palmer, Mr. Field, and Mr. William Maudslay, to whom were shortly added Mr. James Jones, Mr. Charles Collinge, and Mr. James Ashwell. When the Society was constituted, on January 2, 1818, these six young men were joined by two others, Mr. Thomas Maudslay and Mr. John T. Lethbridge, Mr. James Jones acting as Secretary, and during the remainder of that year there was no increase in the number, and there were only three additional members in 1819. In the following year, 1820, when Telford became President, there were thirty-two elections. At the end of 1822, when the Institution had been established five years, there had been fifty-four elections.

Telford's name gave a great impulse to the progress of the Institution, which grew rapidly in importance under his fostering hand, so that at the close of 1827—after an existence of ten years—there had been a total of 158 elections, and by June 3, 1828, when the Charter of Incorporation under the Great Seal was obtained, the number amounted to 185 members. Telford continued to be the President until his decease on September 2, 1834, and at that time the actual number of members on the books (as distinct from the number elected) was 200.

Mr. James Walker, the second President, was elected to that post on January 20, 1835; and after occupying the chair for ten years, he declined to allow himself to be again put in nomination, in consequence of a strong expression of opinion from several influential members, that a shorter period for the term of the office of President had become necessary.

Accordingly, on January 27, 1845, Sir John Rennie was elected President, and served for three years.

Since then the chair has been successively filled by Joshua Field, Sir William Cubitt, James Meadows Rendel, James Simpson, Robert Stephenson, M.P., Joseph Locke, M.P., George Parker Bidder, John Hawkshaw, and John Robinson M'Clean, each of whom has served for two years, the maximum time now allowed by the bye-laws.

It should be mentioned that in the ordinary course of rotation Isambard Kingdom Brunel would have succeeded Robert Stephenson, but Brunel requested that he might not then be put in nomination, owing to ill-health and the pressure of professional duties; and unhappily his early subsequent decease deprived the Society of any future opportunity of electing him.

It must always be a subject of regret to the Profession, that in the annals of the Institution, a member so gifted and accomplished should not appear on their list of Presidents.

At the close of 1836, when the Institution had existed nineteen years, the number of members of all classes who had been elected was 369, and the number of those still remaining on the books was 252, or about five-sevenths of those elected.

At the close of 1860 these numbers were 1535 and 930 respectively, from which it appears that three-fifths of all those elected still belonged to the Institution, being a decline of only one-seventh in the relative proportions after a further existence of twenty-five years.

The average annual effective increase of Members and Associates during the ten years from 1840 to 1850 was 25, and from 1850 to 1860 it was 27, the actual increase in 1859 and 1860 being 37 in each year. The effective increase in each of the five years from 1861 to 1865 inclusive has been 20, 57, 42, 56, and 106.

The number of members of all classes on the books on November 30, 1865, were:—

Honorary Members	20
Members	486
Associates	689
Graduates	8
Total	1,203

or an effective increase in one year of 108 members of all classes.

It will thus be seen that a steady annual increase has been the characteristic of the Institution from its commencement; and it may be noted in this, the forty-eighth year of its existence, that, when it had been established twenty-four years, the number of members was almost exactly one-half of the present number.

Attendance.

The experience of the last few sessions shows us clearly that we may expect the future rate of increase to be at least equal to the past; and the attendance, on the Tuesday evenings discussions shows that the interest attached to the proceedings of the Institution increases in at least an equal proportion with the augmentation of the numbers.

It is now not uncommon to find our meeting-hall inconveniently crowded, and occasionally it is altogether inadequate to accommodate the numbers who desire to be present; and many persons who, from the public interest attached to some of the subjects, desire to hear, or to take part in the discussions, are now prevented by our restricted accommodation from doing so.

Finance.

For some years in the early history of the Institution it was a work of considerable difficulty to keep the disbursements within the receipts, and except for the admirable management of our late Secretary and now Honorary Secretary, Mr. Manby, it is hard to know what difficulties we might not have experienced; it was not until its income became sufficiently increased by the liberal donations of the council and other members, by trust-moneys and bequests, and by the increase in its numbers, that the Institution was in a financial position to give increased accommodation and assistance to its members.

It may be stated that during the last ten years the average increase on the receipts has been forty per cent., whilst the increase in the disbursements has been only twenty per cent.; and that the present amount of the realised property of the Institution may be safely taken at £25,000.

Library.

It will have been observed that considerable improvements have been made in the library of the Institution, and in its arrangements and facilities; and no doubt the Council and Secretary will continue to give this important department their earnest attention, and we may reasonably expect that both the contents of the Library and its accessibility will be still further increased.

Additional facilities.

It is, however, somewhat remarkable that a greater number of members do not avail themselves of the additional opportunities of reference to the Library which have been afforded them; and this brings me at once to the consideration of the important question of the manner in which this Institution may be made more useful to its members.

The state of the finances, as we have already seen, will prudently permit the expenditure of a larger annual sum than we now disburse, and therefore we are at full liberty financially to consider the question of additional accommodation for the Members; and I believe the Library of the Institution would be far more valuable if an arrangement could be made by which it might be kept open in the evenings for a certain number of days in the week, say until nine or ten o'clock. I have ascertained that no practical obstacle to this extension of use exists, and that the additional expense would not be considerable.

Most of the Members of the Institution are necessarily engaged in their ordinary daily professional duties during the only hours when the Library is at present available to them; and it is obvious that it is only in the case of a special reference being required, or for some statistical purpose, that the Library can be useful to Members generally under the present arrangement.

I can say from my own experience that I should have felt it a great boon, as a young man, to have had the opportunity of spending an occasional evening in the Library, and of reading and consulting the rich record of professional learning and experience now collected there, and therefore I throw out this hint respecting the extension of the hours for reading.

Another step might probably be taken with great advantage to students and Engineers generally, viz. the systematic collection of good working drawings, specifications, and contracts for important works in progress or completed, and with facility for reference to them in the Library, and permission to make tracings or copies.

There can be little doubt but Engineers in large practice would permit copies to be taken of their working drawings and specifications for this purpose; and in addition to this assistance with respect to drawings, it would not be difficult to obtain permission for the inspection of the works themselves, during their execution, so that young Engineers might have the opportunity, especially during the summer months, of seeing works as they are carried out, and comparing them with the drawings and specifications to which they have had access in the Library.

Lectures.

I would also venture to suggest that, in addition to the greater advantage which may be conferred on those using the Library by extended time of access to it, and to the collection of working drawings and specifications, with arrangements for inspection of practical works, a limited number of lectures would be very valuable if given by Members who were especially conversant with any given subject, on other evenings than those of the ordinary Meetings during the session of the Institution.

New Building.

I now approach a question in connection with the Institution and its functions upon which, in common with the profession generally, I confess I feel very strongly, and that is, the necessity of providing as soon as possible a building more commodious and more convenient than that which we now possess.

Our rapidly-increasing numbers have already reached the point when, as I have previously stated, the theatre in which we are now assembled is admittedly insufficient for the accommodation of those who wish to attend our discussions; and in addition to inadequate space, there are conditions inseparably attached to the present building which prevent this room being properly ventilated and rendered comfortable.

The other rooms of this building are also totally inadequate for the ordinary purposes for which they are required, and on the evening of our annual *conversazione* especially, the crowding and discomfort are such as to repel many of our best friends from venturing to be present with us.

With a proper building and well-arranged rooms, we shall also be able to have many objects of professional interest for our inspection and study, of which we are at present deprived—such as models of work and machinery, new articles, or new combinations, or, possibly, even a good Museum.

I hope, however, we shall shortly be in a position to consider a distinct proposal for a new building, worthy of the present position and the future requirements of the Institution.

Conclusion.

Having now frankly brought before the Institution some of the more important matters which appear calculated to influence the future of the Members of our profession, permit me to say, in conclusion, that I am not sanguine enough to expect that I shall accomplish more in this Address than direct the thoughts and attention of my professional brethren to the subject, and induce others more able than myself to take it up.

It cannot be doubted that the rapidly increasing prominence and importance of our profession impose upon us grave responsibility and the duty of vigilant watchfulness, so that the character of our Members, and the success of our works, may be all that greater knowledge, wider experience, and more cultivated taste ought to make them, and that every new work of importance may be better than that which has preceded it, and remain as a monument of progress, of which all may be proud.

It is not now sufficient that an engineering work should be durable and free from failure; but, with our present means of study and of knowledge, it will be expected that our works should display in a satisfactory degree the qualities of fitness, economy, and taste, in addition to that of durability.

With deeper study and more complete preparation, the love of our profession and pride in its noble works will become greater and greater in its students, and lead to that intense devotion and application which history teaches us has alone produced the greatest works in art and science; and we cannot doubt that far greater triumphs remain to be, and will be, achieved, by those whom I now see before me, than have yet been realized by either ancient or modern Engineers.

Amidst all the excitement of professional avocations however, let us constantly bear in mind, and endeavour to imitate, the example of the distinguished men who have been removed from amongst us during the last few years, in the happy manner in which they succeeded in combining personal friendship with professional rivalry, and in their never-failing interest in the prosperity and usefulness of this Institution.

January 16 and 23, 1866.

JOHN FOWLER, President,
in the Chair.

The discussion upon the Paper, No. 1,138, "Experiments on the Strength of Cement," &c., occupied both evenings, to the exclusion of any other subject.

January 30, 1866.

JOHN FOWLER, President, in the Chair.

No. 1,114.—"The Craigellachie Viaduct."[1] By WILLIAM HEMINGWAY MILLS, M. Inst. C.E.

THE viaduct constructed for the purpose of carrying the Morayshire Railway over the River Spey, at Craigellachie, Banffshire, is about 15 miles distant from the sea, and consists of four spans, three of 57 feet each on the north bank, and one of 200 feet over the main channel of the river. The works throughout have been constructed for a single line only.

The Spey is one of the largest and most rapid rivers in Scotland; from its rise amongst the Grampian range, till it falls into the sea at the village of Garmouth on the east coast, it is about 110 miles in length, with a fall of upwards of 1,100 feet, and for the 10 miles immediately above the viaduct, the average fall is 1 in 380, or about 14 feet per mile. No portion of the river is navigable for boats, but it is much used for the conveyance of timber, in which a large trade is carried on both for home purposes and for export. The logs or planks are formed into rafts from 40 feet to 50 feet long, and from 20 feet to 30 feet broad, and are floated down to the sea-coast for shipment, or to intermediate points for loading into railway trucks. Not only is the river very rapid, but it is also subject to sudden and heavy floods, for, rising at a great altitude above the sea-level, it receives, early in its course, the drainage of more than 1,000 square miles of mountain range. Numerous rivers of considerable magnitude join it on its way down to the sea, and other tributaries and mountain streams add to its volume, so that at times it will rise as much as from 6 feet to 10 feet in as many hours; and in the summer or autumn, when swollen by heavy rains, it becomes a perfect torrent, frequently bringing down trees, logs from partially-formed rafts, and débris of all kinds; these, acquiring great force from their velocity, tear away the river bank, and destroy any works which are not of a most substantial character. A winter flood, caused by a sudden thaw, after a severe frost and heavy snow, brings large, irregular blocks of ice down with the current, in addition to the increased volume of water. At ordinary seasons the channel is about 180 feet broad, and 4 feet deep in the centre.

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[1] The discussion upon this and the following Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

In designing the viaduct; it was necessary to comply with two points: first, to leave the full channel free for the passage of rafts, and, secondly, to construct, in a massive and substantial manner, the parts exposed to the action of the floods, so as to resist the blows and pressure of the blocks of ice, or the floating timber. The main span is 200 feet in the clear, with a height, from the ordinary water-level to the underside of the girders, of about 20 feet. Of the three remaining spans, each of 57 feet, two are for the passage of flood waters, so that including these with the large span, there is altogether a waterway of about 300 feet. The piers and abutments are of solid ashlar masonry throughout; while the north river bank, upon the upper side of the viaduct, is protected by means of a pitched slope of 3 to 1, the bottom course being secured with short piles and walings.

For the first 9 feet below the bed of the river, the stratum consists of coarse gravel interspersed with large, irregular boulders; after which there is a compact layer of gravel and clay. These boulders vary in weight from 2 cwt. or 3 cwt. to 4 tons or 5 tons each, and are so numerous as to preclude the possibility of advantageously employing an ordinary timber pile coffer-dam. Under these circumstances it was decided to use plain cast-iron cylinder foundations for the river piers and the main abutment, and thick beds of concrete for the land pier and abutment. By this arrangement the foundations proved simple, substantial, and efficient.

The outside diameter of the cylinders in the main pier and abutment is 5 feet, and of those in the small river pier 4 feet 3 inches. The cylinders are in two lengths, each of 6 feet 9 inches, which, when bolted together, form one complete cylinder, 13 feet 6 inches long. The general thickness of the metal is $\frac{7}{8}$ths of an inch; the lower or penetrating edge of the cylinder being made $\frac{1}{2}$ an inch thick, increased gradually to $1\frac{1}{4}$ inch thick, at 4 inches from the bottom. In the smaller of the river piers there are eleven cylinders, in the main abutment fifteen, and in the main pier eighteen; those composing each group being placed as close together as practicable, and all are carried down until the lower or penetrating edge is 13 feet 6 inches below the bed of the river. Before sinking any of the cylinders, the gravel and materials upon the surface at the site of the piers and abutments were removed as far as the water-level. A sufficient space was then enclosed and protected from the ordinary current and flood waters, by means of double rows of small piles and planking, together with bags of clay puddle, placed between and behind them, the piles being driven as close together as the boulders would permit. The enclosed space was next cleared to about 4 feet below the ordinary water-level, the water being pumped out by means of a centrifugal pump, worked by an engine of 12 H.P. The first of the cylinders was then fixed in position. Two hand-pumps, each worked by two men, were sufficient to keep the cylinder clear of water, while a labourer inside excavated the gravel and boulders, emptying the material into boxes, which were lifted by means of a crane. The first cylinder, when thus lowered into position, as far as the ordinary water-level, was used as a well in pumping out the enclosed area. The main pipe of the centrifugal pump was lowered into this cylinder well, and was found sufficient to keep the enclosed space comparatively free from water.

The remainder of the cylinders in the piers and abutments were in the same manner successively lowered into position, but the main body of water being kept down by the centrifugal pump, only one hand-pump was now found necessary. When fairly sunk to the required depth, all the cylinders, and finally the cylinder well, were pumped dry, the ground at the bottom made firm by punning, and the interior filled with concrete in layers. The centrifugal pump was now transferred to an amended position, and the enclosed area pumped dry. The spaces between the tops of the cylinders were then punned and secured with strong squared pitching 18 inches deep, well grouted with lime mortar, at the level of the upper edges of the cylinder. Pumping was continued for a day or two, as a measure of precaution, and to accelerate the hardening of the concrete before the masonry was commenced. The rate of sinking varied considerably, according to the nature of the obstacles encountered, much time being occupied in breaking up with wedges some of the large boulders. The weight of the cylinder, together with that of the framework attached for hand-pumps and men, was generally found sufficient to cause it to descend as the ground below was excavated. Occasionally, however, an additional weight became requisite.

The foundations for the land pier and abutment were carried on in the same way as those of the river pier, and were filled in with a bed of concrete 4 feet thick, brought up in layers, and carefully levelled.

The masonry is of dark red freestone, with the exception of the main girder blocks, which are of granite. The lower foundation course is 2 feet in thickness, and is composed of stones having a large superficial area, many weighing 3 tons. Great attention was paid in arranging this course, so as to get the best distribution of weight over the cylinders. The second foundation course is 16 inches, and the third 14 inches thick ; those in the remainder of the work ranging from 13 inches to 11 inches in height. The face of all the outer stones is left rough or rock-faced, with a marginal draft of 1 inch all round. The coping and mouldings are of dressed ashlar. All the masonry is firmly bedded in good lime mortar, the joints on the face being pointed with Portland cement. The main pier and abutment are 12 feet thick below the coping, and the small piers and land abutment 6 feet thick, with a batter of 1 inch to 1 foot. The three piers have each a pointed cut-water upon the upper or stream side, with a batter of 1 inch to 1 foot.

The girders are of wrought iron 17 feet apart from centre to centre, and carry the railway on the lower flange. For the 57 feet spans, ordinary boiler-plate girders 5 feet deep are used. The vertical plates are ⅝ths of an inch thick at the supports, diminishing gradually to ¼ of an inch at the centre; and are the full depth of the girder, and in widths of 3 feet. T iron, 4½ inches by 2½ inches by ½ inch, is securely riveted on both sides at the vertical joints. The top and bottom flanges, which are alike in section, consist of double angle irons, 4 inches by 4 inches by ⅝ths of an inch; and a horizontal plate, 18 inches by ½ an inch, all riveted together and to the vertical plate, with ¾-inch rivets. The joints both of the angle irons and flange plates, which are arranged so as to occur alternately, are strengthened with double angle-iron joint covers and joint plates.

The girders for the one clear span of 200 feet are on the lattice principle, the depth being 17 feet 4 inches, and the width across the top and bottom flanges is 3 feet. The portion of the girders immediately over the main pier and abutment has a vertical web of boiler plate ⅜ths of an inch thick, the tension and compression bars being riveted on each side. The plates are of the full depth, and in widths of 3 feet, the vertical joints being secured by T irons, 5 inches by 3 inches by ⅝ths of an inch, riveted on each side. The top member of the girder, which is horizontal for the 200 feet, is curved at the supports with a radius of 12 feet, the full section at that place being carried down until it unites with the bottom member. The top and bottom members, which are T shaped, and similar in section, but inverted as to position, consist of horizontal plates 3 feet wide, in lengths of 12 feet, with alternate joints; to these a vertical plate, 16 inches by ⅝ths of an inch, is connected in the centre by means of two angle irons, 4 inches by 4 inches by ⅝ths of an inch. Upon each of the outer edges of the horizontal plates is riveted an angle iron of similar dimensions. The section is thus composed of horizontal plates, a vertical plate, and four angle irons. Cover plates are used to all the angle irons and vertical plates, and a continuous cover plate, 18 inches by ⅝ths of an inch, runs from end to end of both the top and bottom members. Bent plate brackets, 9 inches wide and ⅝ths of an inch thick, are placed on both sides of the vertical plate at every 8 feet in the top and bottom members. For each girder a system of single lattice bars is used. These are placed at an angle of 45°, and are, in horizontal measurement, 4 feet apart from centre to centre. The angle irons, of which the lattice bars consist, vary in section according to their position and relative strain. The lightest, in the centre, is 5 inches by 3½ inches by ½ an inch; the end tension bars are 5 inches by 3½ inches by ¾ of an inch, and the end compression bars are double angle irons, one 5 inches by 3½ inches by ¾ of an inch, and the other 4 inches by 3 inches by ½ an inch. The lattice bars are riveted to the vertical plates of the top and bottom members, with a number of rivets equivalent to the necessary section. At the intersection of the bars nearest the abutment and pier, large malleable iron washers, 8 inches by 8 inches by ⅝ths of an inch, are placed, and securely fastened with five rivets; the remainder of the lattice bars have a washer 3 inches square and ⅝ths of an inch thick, with one rivet in the centre.

The cross girders, which are of wrought iron, and placed 4 feet apart from centre to centre, from end to end of the entire viaduct, are 12 inches in depth, the ends taking their bearing on the angle irons at the vertical plate. The top and bottom flanges consist of double angle irons, 3 inches by 3 inches by ½ an inch, securely riveted to a vertical web of boiler plate, ¼ of an inch thick. The angle irons are carried down at the ends, and form an upright bracket, by which the cross girders are riveted to the vertical plate; a packing plate, of the same thickness as the angle iron, being placed between the end of the cross girders and the vertical plate.

The lattice girders are held together laterally by means of five wrought-iron diaphragms, one being placed at each point of support, one in the centre, and the two others at intermediate distances. These diaphragms are strong frames, of the full depth of the girder, 17 feet 4 inches. The lower member of each diaphragm is similar to a cross girder, but is only 10 inches deep; being thus constructed in order that no portion of the weight of the structure or passing load can be brought upon it, so as in any way to interfere with its duty as a stiffening frame. It is riveted to the vertical plate of the main girder in a similar manner to the cross girders. The vertical members are each divided into two pieces 18 inches broad, placed upon both sides of the series of lattice bars, and are securely riveted together from the top to the bottom. The top member of the diaphragm is 1 foot 4 inches deep in the centre; it is riveted to the vertical plate of the top web of the main girder, and by means of a large plate, 4 feet by 3 feet by ½ an inch, to the main horizontal plates of the top web also. The upper and lower members of the diaphragms are elliptical on the inner outline, gradually joining the perpendicular lines of the vertical members. All the boiler-plate and angle-iron joints are strengthened with suitable cover plates.

The lattice girders and the plate girders for the three small spans are riveted together at the main pier, and thus form one continuous system of girder from end to end of the viaduct. At the main pier the girders are bolted down to the masonry, while at the other piers and abutments the girders rest upon turned cast-iron rollers.

The rails are carried upon two longitudinal timbers, 14 inches by 7 inches, bolted to the cross girders with ¾-inch bolts. The centre and side planking is 2 inches thick, and is nailed on to cross pieces, 6 inches by 3 inches, which are bolted to the cross girders. Longitudinal spaces of ¾ of an inch are left between the side planking. The centre planking is laid close, and covered, almost to the rail level, with strong gravel and broken stones.

The holes for the rivets were in general punched from carefully prepared iron-pattern plates, but in the more important parts, such as the intersections of lattice bars, bolt holes, &c., the holes were drilled.

In the erection of the 57-feet girders no scaffolding was used. These were simply riveted on the ground, and lifted by cranes into position on the small piers and abutment. For the lattice girders a strong temporary wooden bridge, or scaffolding, was constructed for the full length of the span from the main pier to the abutment. The space of 200 feet was divided into six openings of 25 feet each, and one opening of 42 feet for the passage of rafts.

The excavations were commenced May 17th, 1862, and the first cylinder was put into position on July 30th following. The sinking of the cylinders was carried on day and night, every effort being used to get this part of the work finished as soon as possible, both for avoiding risk of damage to the foundations, by flood waters, and also to save cost of pumping. The last cylinder was filled with concrete November 3rd, 1862. - The masonry was commenced June 30th, 1862, and completed November 15th of the same year. The first pile of the service bridge was driven February 7th, 1863, and a line of temporary rails was laid on the top, ready for the conveyance of materials on March 21st. Some heavy floods occurred during the construction of the viaduct, and upon several occasions all progress was suspended for nearly three weeks. When the waters subsided, much time was lost in clearing the site of the foundations, and in restoring the plant, cranes, &c. The first plate of the lattice girders was laid April 6th, and a trial train of engines and wagons was taken over on May 30th, 1863. Much of this expedition was due to the systematic manner in which the girders were first put together at the maker's works. All the parts were there carefully fitted and legibly numbered, so that the pieces, on arriving at the ground, were carried at once to their approximate positions.

In the specification, it was stipulated that the wrought iron should be capable of withstanding a tensile strain of 20 tons per square inch of section. As soon as the angle irons, bars, plates, &c., arrived at the maker's works, specimens were selected, and were subjected to test. The results of several experiments showed, that the average breaking weight of the plates was 22·39 tons per square inch, and of the angle irons 24·16 tons per square inch. The cross girders were tested with a load of 12 tons in the centre, and gave an average deflection of ⅜ths of an inch. The lattice girders were built with a camber of 2½ inches on the tressels, rising gradually from the supports. After the girders were completed, with the cross girders, and when the planking and permanent way were laid, the wedges were struck, and the girders left to swing clear. It was then found that the girders had only settled 1⅜ inch in the centre from their own weight.

At the Government inspection, the viaduct was tested at different speeds, with an arranged train consisting of two engines and heavily loaded wagons, so as to make a moving load equal to 1 ton per lineal foot for the total length of the span. With this load the deflections were found to be as follows:—

First, or land opening of 57 feet,	$\frac{3}{16}$ths	of an inch.
Second ditto	„ ⅛	„
Third ditto	„ $\frac{3}{16}$	„
Lattice girders of 200 feet span	⅞	„

There was no permanent set in any of the girders. When testing the lattice girders, the two engines were placed in the middle of the train of wagons, and the deflection was taken when at the centre of the span. The effective sectional area of the bottom member, deducting for cover-plates, rivets, &c., and as approved by the Government Inspector, is 70 square inches, which, worked out for a moving load of 1 ton per lineal foot for the entire span, gives a tensile strain of 4·10 tons per square inch. In a similar manner, the effective section of the top member, without deducting for cover-plate, is 75·74 square inches, which gives a compressive strain of 3·78 tons per square inch.

The weight of iron in the different portions of the work is as follows:—

	Tons.	cwt.	qrs.
Wrought iron in the plates, angle irons, rivets, &c., of the three 57 feet spans .	45	13	0
Ditto ditto in the cross girders . .	22	6	1
Ditto ditto in the roller frames, bolts, &c..	0	14	0
	68	13	1

	Tons.	cwt.	qrs.
Wrought iron in the plates, angle irons, rivets, &c., of the lattice girders and plated ends	172	9	3
Ditto ditto in the five diaphragms	15	4	0
Ditto ditto in the cross girders	25	1	0
Ditto ditto in the roller frames, bolts, &c.	0	12	2
	213	7	1
Cast iron in the bed plates, and in the rollers for the small girders	5	18	0
Ditto ditto for the lattice girders	6	0	0
Cast iron in the cylinders	157	0	0

Of the wrought iron, the weight of the rivets alone amounted to 16 tons 7 cwt., the number used being about 73,500. There were 504 cubic yards of concrete in the foundations, 27,838 cubic feet of masonry in the whole structure, and 1,672 cubic feet of timber in the bearers and planking.

The cost of the whole structure was as follows:—

	£.	*s.*	*d.*
Foundations, including excavations, cylinders and sinking, concrete, pitching, and pumping	2,774	1	6
Masonry in abutments and piers	3,642	5	0
Ironwork, &c., in the superstructure of the three small openings of 57 feet each, including girders, cross girders, longitudinal bearers, planking, rollers, bed plates, and painting	1,501	12	0
Ironwork, &c., in the superstructure of the 200-feet span, including lattice girders, cross girders, diaphragms, longitudinal bearers, planking, rollers, bed plates, temporary bridge, and painting	4,281	2	10
	£12,199	1	4

As the total length of the viaduct is 413 feet, the cost per lineal foot was £29 10*s.* 9*d.*

The Engineers were Mr. James Samuel, M. Inst. C.E., and the Author. The contractors for the foundations and masonry were Messrs. Mitchell and Ireland, Montrose; and for the ironwork, &c., including the temporary bridge, Messrs. M'Kenzie, Clunes, and Holland, Worcester.

The communication is accompanied by several drawings.

No. 1,145.—"The Grand River Viaduct, Mauritius Railways."[1]

By William Ridley.

The viaduct to be described in this Paper was erected over the Grand River Ravine, on the Midland line of the Mauritius Railways. It was designed by Mr. Hawkshaw (Past-President Inst. C.E.) the Consulting Engineer to the Government of Mauritius, and was constructed by Messrs. Thomas Brassey and Co., the Contractors for the above-named railways, under the superintendence of Mr. Longridge (M. Inst. C.E.), their Agent in the Mauritius.

The total span of the viaduct, from abutment to abutment, is 620 feet, and this distance is divided into five openings of 116 feet each in the clear. The height from the surface of the water to the level of the rails is 129 feet 9 inches (Plate 9, Fig. 1).

Each pier is composed of two cast-iron cylinders, each 10 feet in diameter, resting on masonry foundations, and filled with concrete. The method of constructing the piers is shown in Plate 9. Cylindric rings, 9 feet high, were divided into five segments each, and were bolted together by internal flanges. The horizontal joints were 'rusted up' with iron cement, well beaten in.

The works were commenced May 4th, 1863. The abutment on the Port Louis side was built upon hard tufa, and contains 370 cubic yards of masonry. No. 1 pier was commenced in July 1863, upon a rock projecting on the side of the ravine. The part upon which the pier stands was truly levelled, and the rock well faced up with masonry set in cement. The total amount of masonry in this pier is 92 cubic yards. During the excavation for the foundation of No. 2 pier, considerable trouble was caused, owing to the pier being situated close to the edge of the river, and from the nature of the ground, which consisted of large boulders and fine river gravel, the water freely percolating on all sides of the excavation. This foundation was commenced August 8th, 1863, and was completed September 31st in the same year. At first it was thought, that the water might be kept out by a series of dams (Plate 9, Fig. 4), and with that view a mass of stiff red clay was thrown into the river, and piles were driven as far down as possible, at intervals of about 18 inches; and in front of these were placed a waling piece and sheet piles. When the work was so far completed, a similar row of piles was introduced at a distance of 3 feet 6 inches from the former, the space between the two rows being well puddled, and made as water-tight as possible. The excavation was then continued, and a third and a fourth row of piles were driven, and the excavation again carried down. It was intended, had it proved practicable, to proceed in this manner, placing each dam successively lower than the one in front of it, until the required depth was arrived at. This method proved insufficient, for although the water was, to a great extent, prevented passing through the dams, yet it found its way through the bottom in such quantities, that the employment of steam power became necessary. A centrifugal pump, on Woodford's plan, was now introduced, and was worked by an engine of 14 H.P. When the excavation had reached a depth of 5 feet below the level of the river, the water increased so much, that another similar pump was placed by the side of the first, and in order to render the working of the pumps more effectual, the four straight discharge-pipes, of 4 inches in diameter, were widened out at the discharge ends to a diameter of 8½ inches, giving together an area of 224 square inches. The effect of this alteration was, that nearly twice the amount of water was discharged. The pulley sheaves fixed on the spindles of the pumps were 18 inches in diameter, and were rotated by belts passing over the fly-wheels of the engine, which were each 5 feet in diameter. The number of revolutions made by the pumps was 300 per minute, and the amount of water discharged by the two pumps (after the pipes had been widened out) was nearly 3,000 gallons per minute, or 8 cubic feet per second (Plate 9, Figs. 5 and 6). It was next resolved that the foundations should be laid in blocks of concrete, and that sufficient excavation for one block only should be taken out at a time. The bed of the river adjacent to the pier was of the same material as that which had been excavated—that is to say, it was composed of boulders and gravel; and the river just opposite to the pier was 20 feet deep. Hence, and from the general appearance of the neighbouring ground, it was conjectured that it would be useless to attempt to seek for a foundation upon the solid rock. It was therefore decided, that the excavation should be continued to a depth of 10 feet below the lowest water level, and that the bed of the river should be raised with large stones, so as to be from 3 feet to 4 feet under the same level. In justification of this decision it should be mentioned, that although the depth of the water immediately opposite the pier was, as before stated, 20 feet, yet that depth was quite exceptional, and existed only for a short distance above and below the pier. It was, in fact, a pool of comparatively stagnant water, and might therefore safely be filled up, without fear of increasing the scour in other parts of the river bed. The excavation for the first block of concrete was carried on and piled as shown in Plate 9, Fig. 5. A row of close piling, 8 inches square, was driven as far as possible. This was a tedious and difficult operation, from the quantity and size of the boulders, and from the strong springs of water which came up through the bottom. Owing, however, to the limited area exposed at one time, and the considerable amount of pumping power, the piling was at length got down to the full depth, and was shored horizontally in both directions. A waling piece, 12 inches square, was next bolted to the top, and the whole of the inside of the dam was planked horizontally, and caulked. Drains were cut at the bottom of the excavation to allow the water to run off to the well sunk for the pumps. Tarpaulins were laid in the bottom, and for 4 feet up the sides of the excavation, for the purpose of preventing the numerous springs of water from washing out the cement, and also to turn the water into the drains leading to the pump-well. This plan was found to answer, little cement being washed out. When this block was filled with concrete, a second was excavated and treated in the same manner, the piles between it and the first block being drawn as the concrete was put in. The whole of this foundation was thus successively laid, five blocks of concrete, each 7 feet deep, and measuring respectively 10 feet by 18, 10 feet by 10, 13 feet by 18, 10 feet by 4 feet, and 10 feet by 4 feet, being employed. The concrete was composed of Portland cement 5 parts, sand 6 parts, and broken stone 20 parts. It was laid in layers of 12 inches thick, well punned down, and after every two or three layers it was grouted with cement. Plate 9, Fig. 6, shows a section of the excavation, and the position of the pumps, which were on the site of No. 5 block of concrete. This block, which was the last, was not laid until some days after the others, which were kept dry until well set by working the pumps; when the latter were removed the space occupied by them was filled up with concrete. On this bed of concrete, a block of ashlar, 30 feet 6 inches long, 17 feet 6 inches broad, and 3 feet deep was set in cement, the upper surface being carefully chisel dressed and levelled to receive the sole-plates of the piers.

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[1] The discussion upon this and the preceding Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

The foundation for No. 3 pier was commenced August 5th, and was completed September 30th, 1863; the work being carried on at intervals only. It was of the same description as that of No. 2 pier. A double-acting pump, worked by hand, was sufficient to keep the excavation dry. A bed of concrete, 33 feet by 18 feet by 5 feet thick, was deposited in layers, and treated in a similar way to that already described, and on this a slab of ashlar, 1 foot deep, of the same length and breadth as that of No. 2 pier, was set. The concrete in this case was composed of 5 parts of lime, 5 parts of sand, and 20 parts of broken stone.

No. 4 pier was founded upon rock and hard tufa, some little distance up the side of the ravine; the surface being levelled with cement concrete, on which, as in the other piers, was laid a course of ashlar, 14 inches deep. This foundation was commenced October 14th, and was completed on the 20th of the same month.

No. 2 abutment contains 650 cubic yards of masonry. It was built upon hard tufa, and was commenced August 4th, 1863.

The cast-iron cylinders rested on sole-plates, 2¼ inches thick, which were bolted together with turned bolts. These were levelled and well beaten in with iron cement, between the top of the masonry and the underside of the plates, as were also the joints. The lower ring of each cylinder was 2¼ inches thick, increased at the bottom edge to 3 inches. The other rings were only 1½ inch thick. After the segments were cast, they were bolted together in rings, and mounted on a frame, consisting of two large wheels and a spindle 7 inches in diameter. At first the ring remained fixed, and the spindle, with an arm 5 feet long, to which was attached the cutting tool, was made to revolve; but this not proving satisfactory, the ring was made to revolve on a new cast-iron hollow shaft 12 inches in diameter, whilst the cutting tool remained fixed at the bottom of the frame. The segments for the first rings of each pier were lifted into their places on the works by means of "sheer-legs" and tackle, and in two cases the second rings also; but afterwards a plan designed by Mr. Longridge, was used for lifting the remaining rings (Plate 9, Fig. 7). A mast, A, 23 feet 8 inches long, with a cross tree and struts, was mounted on a frame, C, inside the cylinder, the frame resting on the flanges of the segments, and being supported by small side frames. At B there was another frame, similar to that at C, acting as a guide to the mast, which passed through it in a collar. At the foot of the mast was a pivot, which worked in a foot-piece resting on the top of the frame C, thus enabling it to revolve easily when required. A chain, passing over and lashed to the cross tree, was secured at one end to an eye bolt fixed through one of the bolt holes in the top flange of the ring already completed, whilst to the other was lashed a three-sheave block. The segments were then lifted in the manner shown. An eye bolt and shackle, to which was fixed a two-sheave block, was fastened through a bolt hole in the top of the segment, a 4½ inch 'fall' was passed round these blocks, and led away to a gin crab fixed in the bottom of the ravine. When it was required to raise the mast, a light frame holding two sheaves was laid on the top of the ring just completed, and bolted to its upper flanges; a rope fastened to it passed down under a sheave fixed for the purpose in the foot of the mast, returning up, and passing over the sheaves of the frame to the crab, and the mast was thus raised, taking with it its supporting frames, which had been previously loosened and lashed to the hooks at the sides of the mast; guy ropes being secured to the top, and gently eased away whilst the mast was being lifted. The time occupied in raising these masts was about four hours and a half. In this manner all the piers were erected without a single accident. The mast was 10 inches square, but tapered and rounded at the foot to allow it to turn freely. The cross tree consisted of two planks, each 10 inches by 4 inches, and between the planks, and at their ends, were fixed two sheaves. All the timber work was of teak, and the mast, complete, weighed about 2 tons.

Eleven pairs of rings were thus lifted on No. 1 pier, thirteen on No. 2, thirteen on No. 3, and ten on No. 4. The heights to the top of the last ring on each pier were respectively, 99, 117, 117, and 90 feet, and the weight of each segment lifted was 32 cwt. One set of men in one day lifted the mast and one complete ring. After the cornice pieces of the piers were fixed the masts were removed.

When the piers were in progress, the most convenient method for filling them with concrete was considered. Piers Nos. 1 and 4 were filled from the adjoining abutments; but at piers Nos. 2 and 3, the concrete was lifted by means of an endless ladder. This ladder, with its framework, was worked by a small engine of 5 H.P. (Plate 9, Figs. 8 and 9). A frame was fitted between the columns of the pier, which were 3 feet 6 inches apart, and upon it was mounted a drum, 4 feet in diameter, having cams round its periphery, which caught against the links of the ladder and turned it. A cog-wheel fixed to the spindle of the drum was turned by a pinion on the shaft of the belt wheel. On the top of the cylinders rested another frame holding a similar drum, but without cams. The ladder passed over these drums. The links were each 2 feet long, and were connected together by bolts $\frac{3}{4}$ of an inch in diameter. At every alternate joint was fixed, by angle pieces and diagonal stays, a light deal shelf, sufficiently large to hold a basket containing nearly a cubic foot of concrete. The ladder was of iron 1 inch by $\frac{3}{8}$ths of an inch. The concrete in the cylinders consisted of 2 parts of lime, 3 parts of sand, and 10 of broken stone. When mixed it was put into baskets, which were carried to the tops of the piers by the ladder, where it was lifted off and thrown into the cylinders, the baskets being returned on the underside of the ladder shelves.

Piers Nos. 1 and 4 were filled by a different plan. A frame, 3 feet 9 inches high, was fixed on the top of the columns at the far side of the pier (Fig. 10); a similar frame, but 7 feet 6 inches high, was placed on the abutment, and over these two frames a single contractor's rail, weighing 23 lbs. per lineal yard, was suspended. A box, with a false bottom, was conveyed under the rail, by a sheave rolling over it. When filled with concrete, the box was set loose, and travelled along the rail till it arrived over the centre of the pier. A small line was fixed at the back, by which it could be prevented moving too quickly and striking the frame on the pier. The weight of the box, when filled, was 8½ cwt., and it contained 7 cubic feet. A chain was fixed from the frame on the pier to the foot of the next pier, to guard against any undue strain which might be thrown on it from the concrete box. When the box arrived over the pier, the catch which held up the bottom was withdrawn, allowing it to fall back upon its hinges, and discharge the contents into the cylinders. The box, when emptied, was drawn back by the rope attached to it. The average amount of work done daily in this way was 50 cubic yards, whilst by the endless ladder, at the other piers, about 40 cubic yards were deposited, with one hundred men working at each.

A cylinder, 6 feet long, and 9 inches in diameter, was bedded into the concrete at the top of each column, to serve as a holding-down bolt for the bed-plates, which were lifted in pieces, weighing each 2 tons, by a fall fastened to a slight scaffold made of timber 9 inches square; the ends of the upright posts fitting into the holding-down cylinders. The bed-plates for the tops of the piers weighed 16 tons each, complete, and were cast in eight pieces, bolted together with turned bolts. The upper surfaces upon which rested the expansion rollers and bearing pieces were planed. The bed-plates extended across both cylinders, and were 23 feet 6 inches long by 10 feet wide, and 18 inches deep, the thickness of the metal being 2½ inches. These, when in situ, were wedged up to their proper levels, and beaten in underneath with cement concrete. The concrete was carried up to a height of 3 inches above the tops of the cylinders, and bore the whole weight resting on the piers, the cylinders merely serving the purpose of a casing, and preventing the concrete from crushing laterally (Plate 9^{A}, Fig. 18).

It was originally intended to erect the piers in the following manner:—A length of girders braced together and with roadway plates complete, of about 300 lineal feet, was to have been built at the proper level on the bank of the ravine, and to have been trussed by a standard and by suspension chains (Plate 9^{A}, Fig. 11), and a jib crane fixed at the end. The girders were then to have been pushed forward, until the crane commanded the site of the first pier, when the segments and bed-plates of the piers were to have been run along the girders on bogies, and have been lowered into their places. The concrete was in the same way to have been filled in from the top, and the top bed-plates fixed. Whilst this was in progress, additional lengths of girders were to have been added on the land end, and as soon as the first pier was finished, the girders were to have been advanced another span, and so on till the whole of the piers were completed. But the girders were not ready for shipment till many months after the whole of the cast-iron segments for the piers had arrived in the Mauritius, and therefore the erection of the piers was proceeded with by a separate process, as has already been described. The girders were sent from England in sections of about 12 feet long, which on arrival were transported to the Mahébourg side of the ravine, and were riveted together in lengths of from 36 to 48 feet. A gullet, extending backwards to a distance of about 280 feet, was excavated to the level of the abutment; and it rose at a slope of about 1 in 5 to the formation level, Fig. 11. In this gullet the first lengths of the girders were to be built, and the succeeding sections of 36 or 48 feet were to be brought down the incline into the gullet and added as the first were pushed forwards.

The arrangement for launching the girders was, however, considerably modified in England. This modification may be described as follows:—A keel plate, 3½ inches wide by 1 inch deep was fixed under the centre of each girder, to which it was fastened by countersunk bolts, and this plate passed over shallow grooves turned in the tops of rollers, for the purpose of receiving them, as well as of acting as guides to keep the girders perfectly straight whilst travelling. The rollers were 7 inches in diameter, and rested upon bed-plates, Fig. 12. On one end of them a ratchet was cast, and a space was left outside, to receive a cast-iron lever head; and outside this again an iron ring was bolted, to prevent the lever head from sliding off: a similar ring was fastened on the other end of the roller, to prevent its travelling laterally along its bed-plate. The bed-plates of the rollers were laid upon and bolted to timbers 8 inches deep by 16 inches broad, the latter being laid on a course of ashlar masonry. The rollers were placed 36 feet apart, and were turned by levers each 9 feet long, and between them three lines of rails were laid, upon which a sufficient length of girder for launching was built. The girders were next lowered down upon the rollers, and the levers fixed in their places; a steel pall was bolted to each lever head, which worked in the ratchet cast on the roller, and thus caused it to rotate. Figs. 11 and 12 show the arrangement of the levers and the details of the rollers; also a section of the lower flange of the girder with the steel plate attached to it. The levers were connected together by a rope, securely lashed to their top ends; the lever on the abutment being made in the form of a bell crank, and the rope passed over the ends of its two arms to the winches below, placed in front of the abutment; the whole of the levers, thus connected, worked together simultaneously. The other end of the rope was attached to a crab, which pulled the levers back again when the stroke was completed. As the girders were launched, sections, each 36 feet long, were joined on at the back end.

The launching was commenced on Thursday afternoon, April 18th, 1865, and the girders were propelled forwards a distance of 2 feet 6 inches, at the rate of 1 inch per minute. No further attempt at launching was made until the following Saturday, when the girders were only advanced 1 foot 8 inches, during the whole day. The cause of this failure was due to the keel-plates rolling out; for a portion, 4 feet in length, was elongated 2 inches, and thus jammed against the roller. At first only three sets of rollers *a*, *b*, and *c* (Fig. 11) were laid, but four more sets were subsequently added. The length of girder moved, when the launching was first commenced, was 252 feet, and it weighed about 190 tons, including the tension chains and standards, which trussed the girders during the construction of the piers. One of the great difficulties was the irregularity of the underside of the lower flange of the girder, arising from the cover plates of the joints and the strengthening plates, and also in some measure from the camber of the girder itself.

When the keel plate rolled out, serious doubts were entertained as to the practicability of launching by rollers, on account of the great friction from their turning in their bed-plates, and from the probable continuous elongation of the keel-plates. To overcome this last objection, it was resolved to place loose keels under the fixed ones, to keep them off the rollers. These were made in short lengths of about 4 feet, each 3½ inches wide, and varying in thickness as required by the camber and other irregularities on the under side of the girders, Fig. 13.

On Saturday, April 22nd, another and more successful attempt at launching was made. The introduction of the short keel-plates was found to be a great improvement, ample space being thus afforded for their elongation, in case of rolling out. Some were tapered off at one or both ends, to allow of easy entrance and progress, as will be seen by reference to Fig. 13, in which the manner of their application is also shown. The launching commenced at 11·30 A.M., and was successfully carried on till 4·15 P.M., the girders being propelled a distance of 39 feet in the four hours and forty-five minutes. In addition to the two double-purchase winches working the levers in front of the abutment, a 9-inch rope, reeved round a pair of three sheave blocks, was fixed to the back end of the girder, and was moved by the means before noticed, the strain being reduced by a smaller set of blocks with a 6-inch fall. The number of men employed was 18 at the winches working the levers, 18 at the winches hauling the levers back, 28 at the rollers, following up with the small keel-plates, 14 at the levers, attending to the palls, &c., and 1 engine driver; in all 79.

On the Saturday following, the girders were launched a further distance of 40 feet 6 inches, which was accomplished in five hours; one being spent in readjusting the keel-plates, levers, &c. At each stroke of the levers, the girders were propelled a distance varying from 3 inches to 4 inches.

On Monday, after another launch of 12 feet was effected, the keel-plates over the first rollers completely failed, by buckling over, as shown in Fig. 14. The strain was very great, for a length of 95 feet of girder was overhanging, whilst the rollers were supporting the weight of nearly twice this length. The iron of the keel-plates was crushed by the weight, the rollers in front surged at each stroke, and the lever heads broke across the bottom.

The girders had now to be lifted; the damaged keel-plates to be removed and replaced, as also the broken lever heads. Another attempt was then made, but with little success, the lever heads again breaking, and the keels crushing. These were repaired, and on the following day the girders were propelled 10 feet, after the application of an additional power of two 8-ton jacks at the back end of the girder, when failure again ensued from the same causes. In order to relieve, to some extent, the weight on the first rollers, which were the only ones that failed, 30 permanent way rails, weighing 5 cwt. each, were placed at right angles, lever-wise, under each girder, as near the rollers as possible. Each of these rails acted with a force of 15 cwt., and, together, were to a great degree effective. But still, the launching was unsatisfactory, and was followed by successive failures and breakages, with the additional failure of the front rollers, through their ratchets being stripped of nearly all the cogs or teeth. The girders were, however, finally but with considerable difficulty, landed on the first pier. The deflection of the end of the girder just before it touched the pier was 7 inches.

It was now unmistakably evident, that this mode of launching, simple and effective as it had appeared to be, and good as it was theoretically, was practically a failure, and that the original plan must be resorted to. Figs. 15 and 16 show, in section and elevation, the method now introduced for the portion of the girder resting on the abutment and in the gullet. Throughout the gullet, and up to within 5 feet of the face of the abutment, Fig. 16, a line of flat-bottomed permanent way, the underside of the rails being level with the masonry, was laid under the centre of each girder, and on longitudinal timbers, resting on cross-sleepers. At every 12 feet a baulk of timber, 9 inches square, forming a skid, was placed transversely across the rails; upon these baulks the girders were wedged up. A thin plate of iron was fixed on the underside of each skid, over that part which would bear upon the rails; two bolts passed through it, the heads being let in flush with the surface of the top, whilst the nuts, projecting underneath, came close up to the inside edges of the rails, and acted as guides to keep the girder in line when travelling.

When the girders were ready to be moved, the rails were well greased, and men were placed at the ends of each skid with sledge-hammers to keep striking it to prevent sticking, as well as to assist in starting. The skids, after arriving successively at A, gently pressed over the ends of the rails, dropped, and were removed.

The manner of placing the rollers on the piers is shown in Figs. 17 and 18. On the top of the bed-plates, the bearing plates for the permanent expansion rollers were bolted. These plates were 2¼ inches thick, and were tapered off at the ends, to allow the rollers to enter and pass freely in and out. The latter were linked together, and after travelling over, the plates were taken out, returned, linked on to the rollers just entered, and were gradually drawn in under the girders. Short pieces of keel-plate, in 4 feet lengths, were followed up on the rollers, as the girders advanced, by men stationed on a scaffold.

On May 15, everything was again ready to launch; a ⅞ths of an inch chain, doubled, was secured to the back end of the girders, and passing over a sheave on the edge of the abutment, was fastened to the blocks (Fig. 19). The rope was reeved round a pair of large blocks, that at N being fastened to the foot of the pier, as shown, and led away again to the smaller blocks, over which was reeved a 6½-inch fall, leading to the rope roll on the top of the bank through a snatch block at F. The chain broke after the girders had been moved a few inches. This, however, was removed and replaced by a chain cable 1¾ inch thick, and the day following the girder was launched a further distance of 31 feet 6 inches, when the large block at L broke. This was soon replaced, and the next day, between 1·15, and 4·30, P.M., the girders were advanced a distance of 62 feet 6 inches. The rate of travelling was 12 feet every fifteen minutes, when it became necessary to overhaul the small set of blocks, which occupied twenty minutes each time.

On Thursday, May 18, the girders were on No. 3 pier. On the 24th, No. 2 pier was reached, the greatest distance travelled, as yet, in one day, being 108 feet in four hours. On Saturday, June 10, the girders were landed on the Port Louis abutment, in six hours and twenty minutes, the entire length of the girders, 630 feet, moving quite easily. Another rope was secured to the other end of the girders on its reaching No. 1 pier, and passed round a double purchase winch placed on the Port Louis abutment. Thus an additional motive power was added and the whole of the launching was completed most satisfactorily.

The roadway girders, plates and permanent way, were soon and easily laid; and fourteen days after the launching was finished, trains were running over the viaduct. The entire work was completed on Saturday, the 29th of July. The girders were fixed, at their centres, to the piers, whilst their ends, by resting upon rollers, were free for expansion and contraction. During the launching, rollers were placed upon each pier; these had to be removed when the girders had to be fixed, the latter being lifted for this purpose with two hydraulic jacks, of 50 tons power, and cast iron "making up" pieces inserted.

The total weight of the superstructure is 560 tons, of which 142 tons is the weight of the roadway; and the total weight of ironwork in the piers, including bed-plates, expansion-rollers, &c., is 933 tons.

In conclusion, the Author trusts that the novelty of the design, and the method of carrying it out, will be a sufficient reason for making this communication; as this is the first bridge, to his knowledge, constructed on this plan on so large a scale, where the method of launching the girders as described has been adopted.

The Paper is illustrated by a series of diagrams, from which Plates 9 and 9^A have been compiled.

Mr. J. A. **Longridge** thought the Paper was so complete, that there was scarcely anything left for him to add. The total cost of this viaduct was upwards of £30,000, or about £50 per foot forward. The cast-iron columns which were sent from England, cost, in erecting, about 28*s*. per ton. The expense of launching the girders was considerable, owing to the disasters that were, in the first instance, met with; it amounted to nearly £5. 10*s*. per ton, including the riveting up of the sections of the girders, plant, cutting out the gullet, and labour. Had the plan that was subsequently adopted been proceeded with in the first instance, the launching would probably not have cost more than £3. 10*s*. per ton, as was shown by the fact that one complete span was launched, with the whole weight moved, in about seven hours, by the labour of not more than 100 men. He felt such confidence in the system, that he should not hesitate to adopt it on almost any scale. There were great difficulties in carrying out such a work in the Mauritius from the want of sufficiently strong tackle, but, in a country where all the necessary appliances were at hand, he considered it the cheapest and best way of launching the girders. The cast-iron columns delivered cost £8 per ton, and the cost of transport to the place was about £1 per ton, which added to 28*s*. per ton for erection, made nearly £10. 10*s*. per ton in place. The wrought-iron work delivered in the Mauritius cost £16 per ton, £1 per ton transport, and £23 per ton in place. The land carriage was about 4 miles, over some very steep hills. He would add, that in putting in the concrete in No. 2 pier, the tarpaulin system, which had been originally introduced by Mr. Smeaton, was most successful. There were springs of water from the bottom of the excavation, such as he had seldom seen; but by planking the whole dam in the first instance, and laying down a tarpaulin at the bottom and by pumping, in a few minutes the water did not show a vestige of cement, and when the place was drained for No. 2 block, the cement had set so hard that picks had to be employed to get in the joint. The coral lime, which was the kind used, had no hydraulic properties; but when kept dry, it set extremely hard, and was one of the best he had ever met with.

Mr. G. W. **Hemans** remarked, that the Grand River bridge was an experiment of a striking nature, and one which at first sight almost seemed to threaten failure, but such had not happened. From the height of the columns, the thrust of such long girders upon the rollers must have been very great, and it seemed astonishing that it could have been withstood by the piers without rocking. He thought he should have taken the precaution of tying back the tops of each of the columns, to the feet of the adjoining ones; but that did not seem to have been necessary

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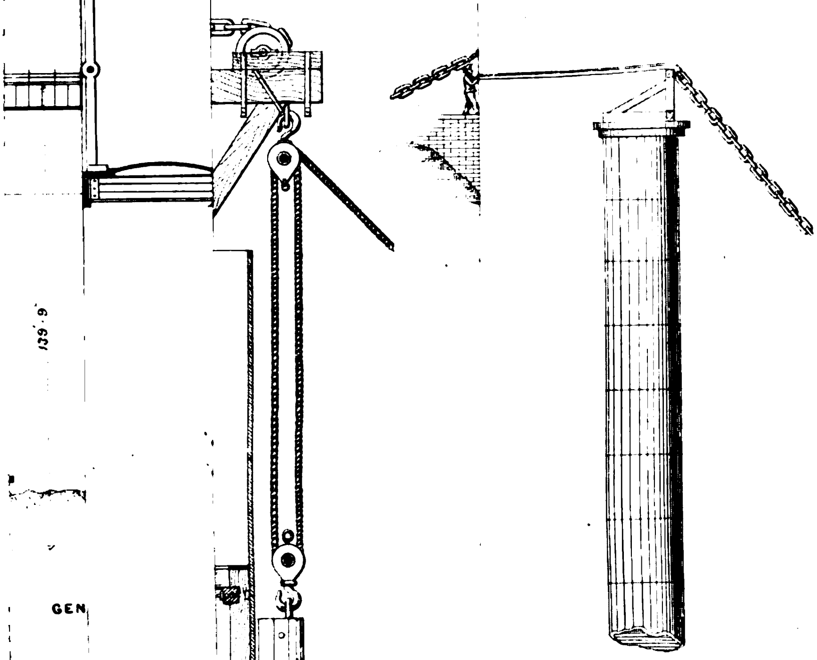
PLATE 9 VOL XXV



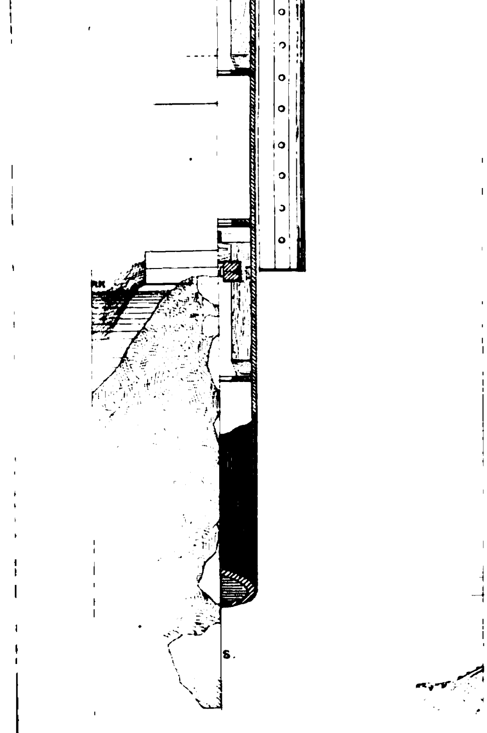
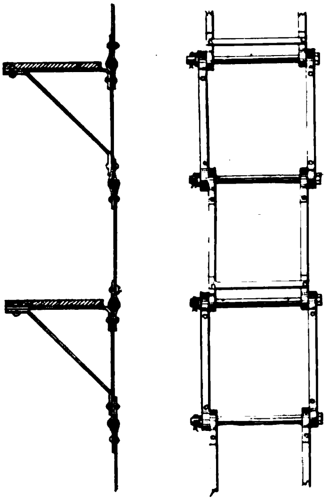


Fig 8.



ivil Engineer

KELL BROS LITHS CASTLE ST HOLBORN

NIVERS
OF

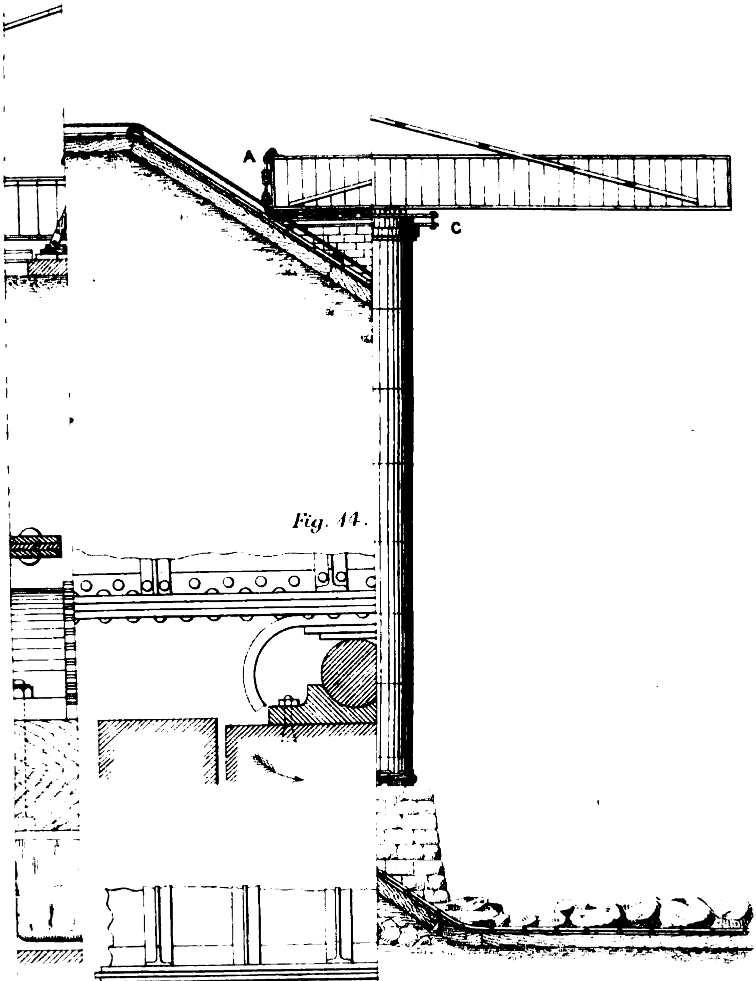


Fig. 14.

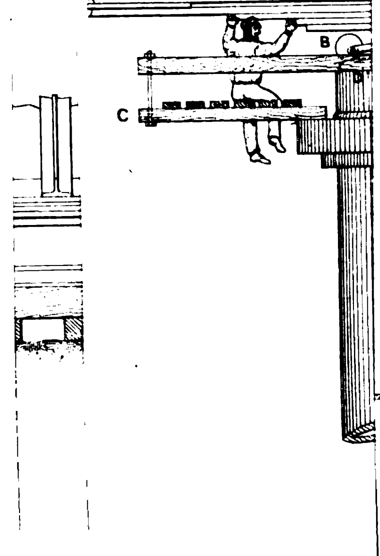
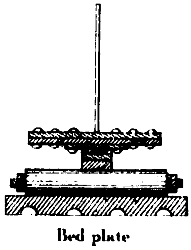


Fig. 18.



Concrete
Cylinder.

SECTION ON PIERS.

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in practice. He should be glad to know, whether any rocking occurred at the tops of the piers, from the thrust of the rolling motion of the girders. He would express his admiration of the skill with which the work had been carried out, and of the ingenuity shown in all the details.

Mr. LONGRIDGE said, he had himself the fear of rocking which had been alluded to; and he had taken the precaution of tying the first and second piers back; but the plumb-line showed that there was no necessity for doing so, and he did not proceed with it farther. The men employed in the operation of launching had the power of putting in any requisite amount of thickness between the rollers and the keel piece. If they found the weight was too heavy, they put in thinner pieces; and they continued this with ease as they went along. The great difficulty was that the keel piece could not resist the weight, and it crushed as the rollers revolved. When the overhanging weight caused a deflection beyond the abutment, it relieved the weight from the rollers behind. If the girder had been perfectly rigid and straight, the plan sent out from England would have answered exceedingly well; but unfortunately the girder was neither, and the plan failed.

Mr. VIGNOLES remarked, that the apprehensions as to rocking from the movement of the girders over the tops of the columns were groundless. The difficulty had arisen from friction at the abutments only, and not from any on the tops of the pillars; and when the beams were moved in the economical way which had been described, it was evident there was no motion over the tops of the cylinders which could have rocked them. The facility with which the girder finally moved from the abutments proved that it passed with ease over the columns. There was one point particularly deserving of attention, which was, that the Author and Resident Engineer, at the time they carried the girders across, had exhibited the possession of resources which enabled them to overcome difficulties on an emergency, and he thought all due credit should be given them; for, finding that by following their original instructions they had failed to effect the object in question, they rapidly and effectually accomplished it by other means.

Mr. J. M. HEPPEL thought that, having been for four years the Engineer of the Madras Railway, before the Mauritius Railways were projected, he ought to state the fact, that in all the large river bridges on that line, the mode of getting the girders in place was precisely similar to that which had been now described. It was true, the spans of the girders were less, being 70 feet from centre to centre, while those of the Grand River Viaduct were 116 feet. The girders of the bridges for the Madras Railway were continuous, principally with the object of getting them into place in this simple and efficient way; and he believed he explained that operation, and illustrated it by diagrams, in his remarks on Mr. Edward Johnston's Paper on the Chey-Air Bridge, read during the last Session.[1] He mentioned on that occasion, that one of the advantages of continuous girders of two spans, was the power afforded of getting them into place in this way. The girders he referred to were connected in lengths of 140 feet, or enough to cover two spans, each length consisting of three pieces, one central piece 36 feet long, and two end pieces, each 52 feet long. By means of strong tackle, he found no difficulty in bringing the girders over the piers by rollers, from one end of the bridge to the other, successively continuing them, one after the other, till the whole series was completed. In the first instance, that of the Palar bridge, he simply used planks and wooden rollers, and met with some difficulties in consequence, which he subsequently surmounted. But by employing inverted rails fixed to the bottom of the girders, and cast-iron rollers on the piers, the superstructures of the bridges over the Cavery, Thoota, and Chey-Air, were erected with perfect success. The adoption of that system on the Madras Railway might have probably induced Mr. Hawkshaw (who was also the Consulting Engineer of that railway), to recommend it in the Mauritius; and he was glad to find that it had been successful on a larger scale than in the case of the Madras Railway.

Mr. R. BROAD said, that instead of greasing the rails, he should have preferred to convert the cross baulks or cross sleepers into axles, with wheels at the ends, resting on a common railway. In that case, it would only have been necessary to repair the railway. The axles should be much stronger than would be required for merely carrying the weight of the girders, and large enough to present a bed on the top for receiving the packing which the men would require for keeping the girders at the right level. Then, as the girder came over the pier, each pair of wheels and axle would drop down, as was done with the sleepers in the present case, and each roller, as it came on, would take its bearing. He had employed that system in the erection of a bridge, under the direction of Mr. Fowler (President Inst. C.E.) about sixteen years ago, and had repeated it many times, in one instance in a bridge about 250 feet long. In his opinion, it was a very economical system. Both girders were got over and the cross girders fixed in ten or twelve days. With the exception he had referred to, he thought the plan described in the Paper was an admirable one.

Mr. G. H. PHIPPS said he would remark, with regard to the

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiv., p. 190.

Craigellachie Viaduct, that it was stated to have been calculated for only 1 ton per foot run for engine load, whereas on a bridge of this length he believed Engineers generally took 1½ ton. As regarded the general construction, there was nothing calling for particular remark, excepting that different angles were sometimes used for the trellis work, and that he thought in this case the angle selected, that of 45°, was the best and most economical.

With respect to the other and more important viaduct on the Mauritius Railways, there were two points of view in which it might be regarded,—one was the nature of the general design, and the other the means adopted in erecting it. On the first there was little to be said—cylindrical columns bearing boiler-plate girders, and those supporting the railway and train above; nothing could be more simple. But the cross-section of the piers suggested to him, that if the iron in the two columns, of 10 feet diameter each, had been disposed in diagonal columns, spread out much more at the foot, like a pyramid, and well braced with wrought iron, the weight might have been superimposed directly upon the iron. The whole of the concrete might then have been dispensed with, which would have reduced the expense materially. He had calculated the dead weight upon the piers, and had it been upon the iron instead of upon the concrete, it would have given a pressure of only ⅓th of a ton on the square inch, which was much less than might have been put upon the iron safely. Had each pier consisted of a cluster of columns well spread out at the foot, its appearance and construction would have been better, nor would it have been more open to the effects of weather, because the iron could have been equally thick. Great praise was due for the manner in which the work had been carried out, and particularly the coffer-dams, which were constructed under remarkable difficulties. In erecting the bridge, it evidently was proper to push the girders over from the end, as was done in this case, whether by the particular plan first sent from this country, or by that which was subsequently adopted, mattered very little. No doubt the great stress was upon the rollers at the end over the piers; but, supposing the rollers to be the same, he could see no reason why the original plan should not have answered.

He would now, for a moment, address himself to a point not generally very popular, namely, the question of priority in the use of the methods of construction described. If those methods were good, it was, of course, well to describe them: still, if a large part of any Paper was taken up with such matter, as on the present occasion, then he thought it was right the question of priority in their use should be put upon its proper footing: because it was not pleasant to those who had originated any plans of construction to find them described and enlarged upon afterwards without acknowledgment, even in the absence of intentional plagiarism.

There was no doubt that a similar plan had been used in India, in the erection of the bridges over the rivers Cavery and Palar, in 1858 and 1860. In those bridges, however, as well as in the Mauritius bridge, the operations were minute, when compared with the extent of a work carried out in Switzerland, the details of which he had in his possession. This was a viaduct for carrying the double line of railway from Lausanne to Fribourg, over the valley of the Sarine (Fig. 1). Its total length was 360 yards, divided into seven openings of 160 feet each, the deepest pier being 262½ feet from the surface of the ground, of which the lower 118 feet was of stone, and the remaining 144½ feet of cast-iron columns, twelve in number.

The total weight of iron work in this bridge was:—

	lbs.
Main girders, &c., roadway, wrought iron	2,640,000
Wrought iron in piers	1,430,000
Cast iron in piers	2,860,000
Total lbs.	6,930,000

The date of the erection of this viaduct was not given; but as there was a model of it in the French Department of Engineering Works in the International Exhibition of 1862, it was no doubt completed before then.[1] In the erection of this bridge the girders were not only pushed over at their proper level from one abutment to the other, but were also made use of as cantilevers for the erection of the piers. Commencing at the abutment, the girders, well braced, were pushed on rollers until the end came over the centre of the intended pier, the materials for which were brought along the railway on the girders, and were lowered down (as by a crane), and fixed in their intended position; the girders were then pushed forward to the site of another pier, and so on. It took sixteen men, working six hours, to draw the girders over each 160 feet opening. The above was so important a work, and so admirably carried out in every respect, that he thought on an occasion of this kind such an instance ought to be referred to. He would add, that, ten years ago, a bridge of about 100 feet span was erected, under his directions, over the Brighton Railway, in a similar manner, by pushing the girders over. That bridge consisted of one span only, and he did not point to it as anything remarkable, but merely to show that the above method of erection was such as an Engineer would naturally resort to.

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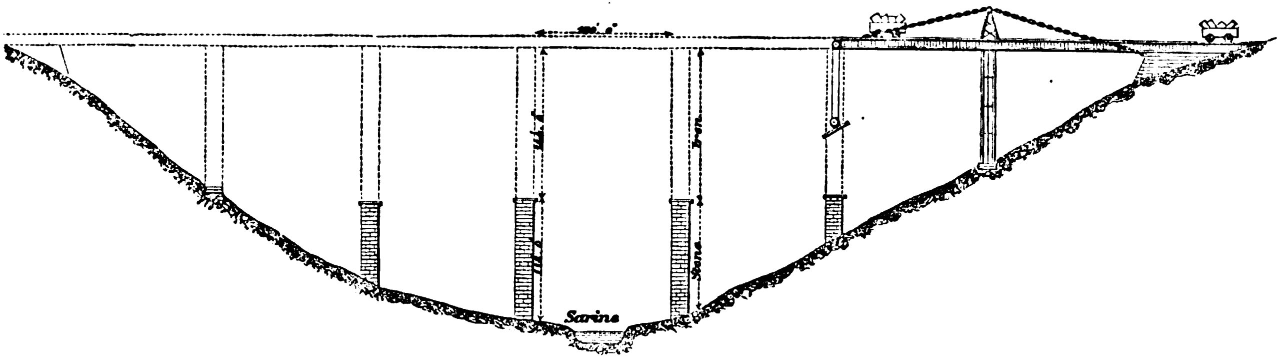
[1] *Vide* "Exposition Universelle a Londres en 1862. Empire Français. Notices sur les Modèles, Castes et Dessins." 8vo., Paris, 1862.

Fig. 1.


Iron
Stone
Sarine

Bridge over the Sarine at Fribourg.

Mr. W. Atkinson said, with regard to the statement, that no permanent set took place in the Craigellachie viaduct when the Government test was applied, that it sometimes happened in building a bridge of that kind, that it was subjected to a severe test, and afterwards no permanent set was observable. A lattice-bridge, with which he was acquainted, of about the same dimensions and height as that at Craigellachie took a permanent set of half an inch with a test of 1¼ ton per foot, though when the Government test was applied, no further set took place. He did not know whether that was attributable to the want of good work in the structure, or whether it was likely to arise in all bridges of such a span and design.

Mr. J. H. Porter remarked, he did not gather from the last Paper or from the drawings, whether the Grand River viaduct was constructed as a continuous girder, or as several distinct girders. In the experience he had had in erecting a bridge of three spans of 100 feet each, he treated it as a continuous girder:—that was to say, the sections of the girders were heavy over the piers and comparatively light in other parts; and in passing a bridge so constructed over any of the spans, there was, he need scarcely say, a point at the intersection of the curves of contrary flexure which, if treated theoretically, gave but little sectional area to resist the great strains from the leverage of the overhanging weight as it arrived at that point. The form of the Grand River Bridge was obviously well contrived for the purpose of passing the structure over in that way. It was more difficult to deal with an ordinary road bridge, where the road was carried at the bottom on cross-girders, and the main girders were 18 feet or 20 feet apart. He was rather struck by the different ways in which the foundations of that bridge and of the Craigellachie viaduct were put in. In both cases it seemed the materials to be operated upon were boulders and sand. In the one case, cylinders were thought to be the best means of dealing with such materials, as opposed to piling and coffer-dams, and upon those cylinders the masonry was built as the permanent bottom, to withstand the shock of timber floating down the river; but in the other case, where cast-iron cylinders were adopted as the superstructure, it seemed strange that the same plan should not have been used for getting in the foundations. Cast iron would apparently have been as suitable for the purpose as in the other case, notwithstanding the percolation of water was freely going on. On a recent occasion the subject of cements, and concrete formed with cement,[1] was discussed, and also the practicability of lowering concrete formed with Portland cement through water and discharging it from below with properly-constructed apparatus for the purpose. Probably that was not generally understood to be a satisfactory mode of doing it, from the fear of the cement washing out; but he thought in the case of those foundations, it was a plan which would have been found to answer.

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[1] *Vide ante*, p. 66.

Sir **Charles Fox** begged to mention a case of some interest—not however from a desire to claim any merit of priority in this mode of moving girders into their places. About the year 1851 a bridge, which was built upon caissons, for carrying the Paris and Lyons Railway over the River Saone at Lyons, unfortunately fell down, the sand under the foundations of one of the piers having been washed away, in consequence of the fouling with it of a large barge laden with iron. The bridge was of stone, consisting of four arches, each of 100 feet span. As the early opening of the Railway was of importance, it was thought better to put up a wrought-iron bridge, instead of rebuilding the original one in masonry. The pier consisted of three cast-iron cylinders of 10 feet diameter each, sunk into the bed of the Saone to a depth of more than 50 feet. The platform sustaining the permanent way, was laid on the top of four girders; which resting on a sort of shelf formed by the masonry of the abutment below, had their tops level with the upper surface of the abutment, and consequently the undersides of the girders were supported on a pier in the centre of the bridge about 15 feet or 16 feet lower than the top of the abutment itself, and of course level with the shelf referred to. Those girders, about 215 feet long, and 15 or 16 feet in depth, each weighing from 105 to 110 tons, were all put into their places without the use of scaffolding. Each girder was built at such an angle that, in consequence of the difference of the height of the pier as compared with that of the top of the abutment, by simple gravitation on rollers, and being at the time what was called "held by the tail," it was allowed to roll down to the proper level to insure its coming upon the top of the pier when it crossed the opening. In the first place all the four girders on each abutment were moved about half way over the span, and were then left as cantilevers, having their ends held down by bolts which passed through into land arches below, and were then in a condition to carry a sufficient load on their cantilevered ends. Under these ends were firmly fixed two baulks of timber, for the purpose of carrying a roller which was successively placed under each of the girders, and then by mere gravitation, each girder moved over the span, until its end was lodged on the top of the pier. When that was done, the other end, by means of screw-jacks, was lowered on to the shelf already described, and the operation was completed. The reason why scaffolding was not employed was, that the quantity of débris of the fallen bridge in the bed of the river was such that it would have been impracticable to drive ordinary piles through it. He would add that one disadvantage in piers of a pyramidal or conical form was, that if cast iron was used in their construction, it was hardly possible to deliver the materials on the other side of the globe without some breakages, and therefore the number of spare pieces required to be sent out must be much greater than when cylinders were employed; as in the latter case, all the plates of which they were formed might be alike.

Mr. HAWKSHAW, Past-President, said, the questions of manipulation in erecting structures of the kind alluded to were so various, and depended so much upon local circumstances, and upon the appliances which could be commanded at particular places, that the modes were certain to be changed by Engineers in different countries. With regard to the method of launching used in the Grand River Bridge, it had been adopted on the Madras Railway some years before it was applied to that bridge; and other bridges of greater length were erected much in the same way; but though the bridges were longer, the spans were not quite so large, still the principle of the launching was the same. Sir Charles Fox had given an instance under his own superintendence.

With regard to that part of the bridge with which he was personally concerned, the design, he would say a few words. He agreed, that if that bridge had been erected in England, the mode in which the piers were formed would possibly not have been the one he should have adopted. But it showed the necessity, on these occasions, of understanding all the circumstances, before any conclusion could be arrived at, as to whether the plan was good or bad. It had been said, if instead of having two columns of considerable diameter to every pier, a greater number of smaller columns had been used, and the base widened, sufficient stability would have been obtained. He agreed with that remark; but two things had been overlooked. First, the spreading of the base would have required much larger foundations, which, as had been seen, were troublesome to form at that place; and next, in planning a work of that sort, the design must have reference to the situation. It therefore occurred to him, that there was no better way—and he was of the same opinion still—than to design it so that one simple casting only, apart from the base plates, would be sufficient to form the piers. By adopting that plan, and by dividing each ring of the cylinders into five segments, a repetition of the same casting enabled these piers to be built to any height that might be necessary. The castings required no fitting after their arrival. It was only necessary to send a sufficient number of the same plate with a due supply of bolts to fasten them together; so that nothing was required in the Mauritius but to build and bolt one on to the other. If he had adopted piers of a pyramidal form, so far from getting a repetition of a single casting, there would have been many pieces differing in dimensions; the diagonals must have varied, and a much larger amount of fitting would have been involved. Then the island was volcanic in its origin, and, though stone could be found of which to make concrete, procuring suitable material for masonry was a very difficult matter: that was another reason for adopting that mode of forming the piers. He believed, in fact, looking to the rapidity of execution, and considering that the whole of the iron-work had to be sent to a distant country, where the work of erection must be done by a small staff, where fitters could not be procured, and where the wages of men sent from England were very high, that it was the best mode of construction that could be adopted for the locality.

But, after all, such questions must always be matter of individual opinion. One great advantage of these discussions was the opportunity afforded of eliciting from the Members their views upon details of construction. He did not know to what extent a claim to originality had been put forth for the method used in placing the girders of the Grand River Bridge, but such a claim could not be well sustained. He remembered, when this bridge was being discussed, another mode of construction was suggested which was very ingenious, but it was not adopted because a design was arrived at more simple and more effective. There was one observation which he should not like to pass unnoticed, as it might lead to an erroneous conclusion. It seemed to have been thought, that all Engineers necessarily assumed a load of 1½ ton per foot for each line of way. That was not so; nor was it necessary. In many cases it would be unwise. For instance, in large bridges with several lines of way, it would lead to an excessive waste of iron. Therefore it should not be accepted that Engineers generally adopted such a rule. On the Charing Cross Bridge, the Board of Trade had required 1 ton per foot on each line of way; and in general the rules required that malleable iron should not be subject to a strain of more than 5 tons to the inch. But individual judgment must always be exercised, as to whether the load applied was the proper load or not. No precise rule could be laid down for the weight per foot, because on a short bridge it might be necessary to have more than 1½ ton per foot. A bridge might be so short that all the wheels of the engine would rest upon the girder, while the ends overhung the bridge; but if the bridge were of great length it would be absurd to suppose it could ever be entirely covered with locomotives; therefore all these questions must be decided with relation to the position and size of the bridge.

Mr. G. W. Hemans thought it might be accepted as a recognized principle, that in bridges of about 30 feet span and under, which could only contain one locomotive with overhanging ends, the requirement was about 2 tons per running load to the lineal foot. In bridges which would contain two or more locomotives with their tenders, 1 ton per lineal foot was the weight generally expected to be met, in addition to the weight of the bridge itself, with a strain not exceeding 5 tons to the square inch. If those requirements were observed, the Government Inspectors would be satisfied.

Mr. Atkinson could state, that on bridges of about 200 feet span the requirement was about 1¼ ton per lineal foot, assuming the train to be made up of locomotives and tenders. If, as had been stated, the span was only about 20 feet, then a load of as much as 1·8 ton or 1·9 ton per foot could be brought upon the bridge.

Mr. Cubitt, V. P., remarked, that he was never asked by the Officers of the Board of Trade for more than 1 ton per lineal foot in a long bridge, and 1½ ton per lineal foot in shorter bridges, for each line of way.

Mr. T. E. Harrison said, that no rule had been laid down by the Officers of the Board of Trade as to weights. In his own experience the requirements had varied very much, and he thought it would be a great boon if some guiding rule were adopted. With regard to the Craigellachie Viaduct, having minutely inspected the structure, he was happy to bear testimony that, as an engineering work, it was exceedingly well executed.

Sir Charles Fox observed, on the question of load on short girders, that if a locomotive engine, 30 feet long, with a wheel-base of 15 feet, were placed upon a bridge with girders of 20 feet span, the whole weight would come upon these girders, while if the same engine were put upon a bridge of 30 feet span, the load would remain only the same. It was, in fact, the difference only of 10 feet being taken up by the projecting ends of the engine, which gave no additional weight upon the girders.

Mr. Hawkshaw, Past-President, said, it happened, as far as he was individually concerned, that he had never experienced much difficulty in satisfying the Officers of the Board of Trade in the works he had constructed, when he considered he had reasonable grounds for the course he pursued; and he thought it was somewhat hard upon officers of the Royal Engineers, that they should be called upon to be precisely definite in their views as to weights and loads, and modes of construction, when they heard how Civil Engineers varied on those subjects. He undertook to say, if four or five Engineers were sent to investigate the strains on those bridges, and to act upon their own opinions, they would probably be found more troublesome than the officers of the Royal Engineers, who, he felt bound to say, had sometimes very arduous duties thrown upon them. They were called on suddenly to say whether a railway, upon which there were large works, was safe for the public, and they had to pronounce promptly upon that question; and he thought, as far as his experience went, they were usually amenable to reason. He should be sorry to hear of any rigid rule being laid down, as he did not know anything that would tend more to shackle the progress of public works. When the Girder Commission sat, many years ago, he attended and gave evidence before it. He remembered that it was then suggested, that the Commission should lay down rules with regard to the length of cast-iron girders. It was urged that no cast-iron girder should be longer than 35 or 40 feet. He protested against such a regulation being propounded; and he gave the best possible illustration of his feeling on the subject, by erecting a bridge near Huddersfield, with cast-iron girders, which, if he remembered rightly, were 50 feet long. If that rule had been laid down, it would have prevented him building the bridge in a way that perfectly answered its purpose, and on a plan more economical than any other he could have adopted; and that bridge still continued to carry trains. The same remark applied to other rules that might be laid down. Progress was being made; and this rule of 5 tons to the square inch was seen, in some cases, to be mischievous. When he commenced building the Charing Cross Bridge, he was importuned by the manufacturers of steel to use that material. He was desirous of doing so; and he saw his way to making a better bridge by using steel instead of malleable iron. But he found that the Board of Trade had decided, that the tensile strain should not exceed 5 tons to the square inch; and he could not use steel under that rule. Steel might at once be used in bridges, if there was a certainty of there being an allowance of strain equal to the quality of the material. That was another instance of the way in which rules rather retarded than helped forward Civil Engineering. It would be better for Engineers to follow the results of experience, and endeavour to convince the Board of Trade that they had adapted the structure to the material employed, and that they were not afraid of the results.

Mr. Phipps, in his observations upon the Craigellachie bridge, had not at all intended to comment upon the Officers of the Board of Trade. It had certainly been his opinion that Engineers had recently been in the habit of allowing more than 1 ton per foot run; and he knew one instance —namely, in the calculations for the Forth bridge, for which the Act was obtained last session—where 1¼ ton was allowed for the rolling load. He had been under the impression, that the Board of Trade regulations demanded on long bridges as much as 1¼ or 1½ ton per foot, and that with this loading, plus the weight of the bridge itself, the tensile strain should not exceed 5 tons on the square inch. He thought it would be more satisfactory if the weight per foot run, on given spans, were determined by authority, rather than left to individual judgment, because then all would know upon what basis the strain on the booms was arrived at. It would be the same for all Engineers, and therefore there would be no hardship.

Mr. J. FREEMAN entirely agreed as to the inconvenience of being guided by set rules, in reference to the strain upon iron. He thought it better to leave it to the Civil Engineer, who had his reputation at stake, and was naturally jealous for that reputation.

Mr. BERKLEY thought the supervision of the Officers of the Board of Trade was valuable. However much Engineers desired to do what was right, the bringing them into contact with gentlemen who, though they might not have all the practical experience of the Engineer in the construction of railways, desired to see that the structures were designed so as to be perfectly safe, and who had special and extensive experience relating to accidents on railways, was an advantage. He agreed with what had been said as to the undesirableness of fixed rules being laid down relating to the strain per square inch on parts of bridges. It seemed to him that, where the weights passing over structures, and the quality of materials used, were from time to time being changed, it would be improper to lay down such fixed rules; because it would tend to shackle the exercise of that discretion of the Engineer which might be advantageous to those by whom he was employed. On the subject of moving loads on bridges, he would remark that he had calculated what the maximum weight would be per foot run on structures of different spans. All Engineers could do that; but even then they could not fix a rule for all time, because the weight of engines was varied to meet the demands of traffic, or other circumstances, and therefore the load varied per foot run; also the quality of the materials used was altered, and, therefore, different amounts of strains per square inch should be allowed.

Mr. LONGRIDGE said, with the exception of the sentence in which the Author stated that the Grand River Viaduct was the first instance, within his knowledge, in which the method of placing the girders had been carried out to the same extent, he believed there was no paragraph in the Paper bearing upon the originality of the structure. No priority was claimed. The plan was novel to him. He was not aware of those instances which had occurred in Switzerland, or of what had been done in India. The work had to be carried over a great ravine, where scaffolding would have been expensive; the simple and natural way, therefore, was to push the girders across. It was remarkable that a similar idea occurred to him, for building the piers, to that mentioned as having been carried out in the bridge referred to near Lausanne. It was at one time intended to project the girder as a cantilever; the piers were to be built from the girders, and the girders pushed over; but the girders did not arrive till many months after the iron work of the piers, which rendered the mode of launching actually adopted compulsory. He had pushed a girder of 130 feet span over the Tolly's Canal, on the Calcutta and South Eastern Railway, which was done on rollers in about four hours. It had been remarked that, in a case of this kind, rollers would have been better than skids; but rollers could not be obtained in the Mauritius, where there were only small foundries, and where a shilling per pound was charged for the simplest castings. The skids answered very well. On the whole, he thought it was an excellent plan of getting girders across, and he should not hesitate to carry it out on a larger scale.

Mr. FOWLER, President, remarked that many years ago he built a bridge of two spans of 170 feet each, across the Trent, at Gainsborough, and, with the assistance of Mr. Fairbairn, he adopted the plan of launching on rollers. The girders rested, in the first place, on the embankment near the bridge, and by means of rollers and tackle they were drawn over the middle pier, and in that way the two main girders were got over the pier. That was in the year 1847; the embankment was on bad ground, which settled rapidly of its own accord, and still more with the weight of the girder; and it was an arduous work to keep the rollers in position, and prevent the girders from straining.

With respect to the practice of the Board of Trade, he fully agreed that it was most undesirable, and would be mischievous to lay down too many rules, because the circumstances were scarcely ever the same. In the first place, a bridge might be constructed where the heavy trains of a great trunk line passed over it; or it might be built in a situation where it was impossible to have heavy engines—such as branch lines in the North of Scotland, which could not be used as part of the main line, and for which light engines were the best suited. It was surely a great mistake to lay down an absolute rule that, in all cases, the same strain was to be calculated per foot run. That was irrespective of material; but with reference to steel and different qualities of iron, it would be an impediment to future progress, if rules were made equally applicable to all kinds of materials. He looked forward to great improvements in the manufacture of iron and steel for structures of that class; and he had no doubt, the Board of Trade would modify their calculations to meet those improvements. Therefore, it was undesirable that the rules should be made more rigid. This was a matter of such importance that, having had a good deal of experience with the Board of Trade, he could not refrain from saying a word in confirmation of the undesirability of too many rules being laid down. Then, as to the records of failure mentioned in the second Paper, these were records only of temporary failures, without which the description of a great work would have been incomplete.

February 6, 1866.

JOHN FOWLER, President,
in the Chair.

The following Candidates were balloted for and duly elected: —Charles Robert Atkinson, George Rowden Burnell, Francis Fowler, Charles Douglas Fox, Henry Gale, William Bourne Lewis, Robert Aspland Marillier, William Mason, Thomas Penn, Frederick Thomas Turner, and Alfred Harris Vaux, as Members; Henry Purdon Bell, Robert Broad, John Brown, Jun., Robert Harvey Burnett, Thomas Codrington, Charles Campbell Downes, Francis Stacker Dutton, Samuel Tate Freeman, Charles Frewer, Easton Gibb, Charles Gilpin, M.P., William George Granville Vernon Harcourt, Q.C., William Harrison, Edward Barber Humble, Frederick James, William Harrington Lucas, Edward Monson, Frederick Newman, Lieut.-Colonel Peter Pierce Lyons O'Connell, R.E., Joseph Robinson, and Henry Wyndham, as Associates.

The discussion upon the Papers No. 1,114, on "The Craigellachie Viaduct," and No. 1,145, on "The Grand River Viaduct, Mauritius Railways," was continued throughout the Meeting, to the exclusion of any other subject.

February 13, 1866.

JOHN FOWLER, President,
in the Chair.

No. 1,137.—"On the Design and Arrangement of Railway Stations, Repairing Shops, Engine Sheds, &c."[1] By WILLIAM HUMBER, Assoc. Inst. C.E.

THE rapid development of the railway systems in England and in other countries, has, necessarily, directed attention to the study of station arrangements; but the diversity of interests to be considered, the changes involved by a constantly-increasing traffic, and the new and unexpected demands that have been made for accommodation, have prevented, in this instance, that general exchange of idea which has attended the progress of other branches of engineering. Hence the subject was not regularly brought before the engineering profession until a comparatively recent date; when, in 1858, a comprehensive Paper on railway stations was read at the Institution by Mr. R. Jacomb Hood, M. Inst. C.E.[2] So far as regarded terminal and intermediate stations, that Paper touched upon most of the points of importance; but to one class—the arrangement of which is perhaps the most difficult of any that the Engineer can be called upon to undertake—no reference was made. At New Street, Birmingham, there is a description of station neither entirely terminal nor entirely intermediate, but which may be termed 'terminal-intermediate,' as being a combination of both kinds. There is also another part of the subject requiring special notice, viz., that of goods and locomotive stations, which Mr. Hood was compelled to leave untouched. It will be the main object of the Author to supply information upon these heads, by submitting to the Institution the details of the principal metropolitan and other railway stations, both terminal and 'terminal-intermediate.'

The classification adopted by Mr. Hood, viz., that of passenger stations; goods yards, wharves, and depôts; locomotive and carriage sheds; manufactories, and workshops, will be adhered to. The latter classes will be illustrated by the goods station of the London terminus of the Great Northern Railway; the Battersea workshops of the London, Chatham, and Dover Railway; and the carriage and wagon factory of Messrs. Brown, Marshall, and Co., at Birmingham.

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[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xvii. pp. 449—481.

The leading principles to be observed in general, are—proximity to the town, or most popular part of the neighbourhood which the stations are to serve; facility of access; and available space for present and future requirements. Each of these is capable of being further subdivided; but the limits of this Paper will only allow a brief remark on each.

With regard to the first two requirements, it is desirable that terminal stations should be as near as possible to the great central avenues of traffic, without being actually in them; for in the latter case the traffic of the thoroughfare and that of the railway would become intermixed, and thereby impeded. For stations generally, a site should be selected where the surface of the ground is near to the level of the platforms; and if this be not practicable, inclines should be formed, and a sufficient space excavated, or embanked, in order to carry on the works on a level with the platform. All steps, gangway ladders, &c., should be dispensed with: the use of them is only justifiable where no other plan can be adopted. Beyond the station, however, a variation of the surface will be an advantage, by enabling level crossings in the streets and roads to be avoided. The possible contingency of having to extend the line, or to enlarge the station, should also be provided for, by a careful inspection of the surrounding and contiguous ground, and by laying out the first plans in such a manner as to admit of this enlargement, without involving the destruction of any permanent building, or the disarrangement of the existing accommodation. Upon the observance of these conditions will greatly depend the power of limiting the expenditure of money, and of abbreviating the time required to carry out improvements.

Terminal passenger stations are usually arranged under one of three systems,—that in which the booking-offices are placed on the departure side; that in which their situation is at the ends of the lines of rail, and transverse to them; and that in which the lines of rail diverge into a fork, having the offices between. Examples of these systems are to be seen at the Victoria Station,[1] Pimlico, and at the Euston Terminus of the London and North Western. (Plate 10, Fig. 1.) The Victoria Station may be regarded as illustrating two principles, that part of it occupied by the London, Chatham, and Dover Company having the booking-offices on the departure side, and that belonging to the London, Brighton, and South Coast having them at the end of, and at right angles to the rails. There can be no doubt, that the first plan affords, in the words of Mr.

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[1] Plans of the London, Chatham, and Dover, and the London, Brighton, and South Coast, Victoria Stations are published in the "Records of Modern Engineering" for 1863.

Hood, "facilities for giving the greatest length of setting down pavement," and is useful for a system of traffic in which the trains are very extensive, and arrive and depart at distant intervals. But, though a large amount of platform accommodation is of importance, it is a question, whether the length of the arrival platform should exceed that of the longest train. A departure platform, so proportioned, has the recommendation of readily admitting a second train behind the one about to start; yet, without great attention, the attempt to book for two trains at the same time will lead to confusion. Sometimes the platform is arranged in steps, with a view to assign a distinct line of rails for each train; but by this plan some of the trains become inconveniently distant from the booking-offices, and the portion of the line between the head of the last train and the departure-end of the shed is comparatively useless. Where the traffic is of a mixed character, involving the despatch of trains to different parts in quick succession, the second system is no doubt the best; and is, indeed, perfectly fitted for any traffic, if the shed be capable of containing the longest train which the traffic will require. This system also secures a great width of frontage, and allows of the booking-offices being distinct, and opposite their several platforms. It is possible, however, that, at terminal stations in large towns, a combination of the parallel and transverse systems might be employed with advantage. The third principle is illustrated by the Euston Terminus. The ample area of the great hall, with the booking-offices on each side, is conducive to the comfort of the passengers; but the plan of placing the departure platforms on either side, and starting the trains from both, seems open to the objection of causing confusion. The London Bridge Station of the South Eastern Railway, before the extension of the line to Charing Cross, may be cited as an instance of how an immense traffic can be worked in an inconvenient position and a restricted space, by a combination, to a certain extent, of the three systems. Accommodation was thus provided for the South Eastern main line, and the North Kent, Mid Kent, and Greenwich lines. Nowhere were so many trains despatched in the same time as from this station; and it is doubtful whether, except by the plan which was adopted, such an extensive and complicated traffic could have been conducted. It is not, however, intended to adduce this station as a pattern of arrangement, for its history is that of a gradual adaptation to successive requirements.

The through, local, and excursion traffic should each be distinct, so that a passenger, on entering the station, may at once see where to obtain his ticket and find his train. Every facility should be afforded for receiving, labelling, and despatching luggage. Too much attention can hardly be paid to this detail, and also to the situation of the left-luggage and cloak-rooms. Those at the Paddington Station of the Great Western Railway are very convenient. Waiting and refreshment-rooms should be of ample size and readily accessible. It is well to separate the in and the out parcels offices from the general traffic; and this can mostly be done, by placing them at the end of the platform furthest from the passenger and carriage entrances, as at King's Cross and at Paddington. The lamp rooms should serve both for the arrival and the departure trains, as at the Great Western at Paddington, where their position is below the platforms and lines, the lamps being raised and lowered by hydraulic lifts.

In the urinals, &c. for passengers, slate has been generally used, but it does not appear to be so well adapted for cleanliness as white enamelled slabs, or glazed tiles. Both closets and urinals should be arranged to perform the maximum of duty with the minimum waste of water. The small glazed basins require less than half the quantity of water needed in the slate arrangement, besides being always free from bad odour. At the Knottingley station, where the two plans are in use, the superiority of the former is obvious. Closets should flush on opening and shutting the door, and the walls should be lined with a material not easily defaced. Lavatories for the use of first and second class passengers, might, at both terminal and junction stations, advantageously be provided, and would, no doubt, be largely used, even if a small charge were made. The platforms for passengers should be spacious. For through traffic, at terminal and junction stations, the width should not be less than 30 feet. For local trains, docks may be taken out of the extreme end of these platforms, as at King's Cross, leaving the wider part of the platform for the long trains. In order that the passengers may enter and leave the carriages easily and safely, it is essential that the platforms be level with the floors of the carriages, or certainly not below the upper step; many accidents have arisen, and the passengers in their ingress and egress are much impeded, by the neglect of this precaution. The stations of the Metropolitan Railway afford good examples of arrangement in this respect. Turn-tables should not be placed on the main line, or where engines or trains pass over them when not in use, as the ends of the rails and the rolling stock are injured by the constant hammering of the wheels. The use of traversers, especially when light and easily worked, cannot fail to conduce to economy.

At terminal, terminal intermediate, and large junction stations, where there is space available, the greater portion may be roofed in, as that part not required for the traffic will be found useful as standing room for empty carriages. If it be not possible, or expedient, to construct the roof in one span, the intermediate supports should be placed in the centre of a wide platform, in order to be free from the danger of collision, in the event of an engine or carriage getting off the rails. An accident of this description occurred a few years since, at the Bricklayers' Arms Station, where the roof was, in consequence, to a large extent destroyed. The height of a station roof is of far more importance than has hitherto been supposed; when it is very low, no contrivance can secure a proper amount of ventilation. The general impression, that a building roofed with iron and glass must be exceedingly hot during the summer months, has probably arisen chiefly from the insufficient height which is sometimes given to such structures. Gas, throughout all stations, is preferable to any other means of lighting; and there are few places where it cannot be employed with economy. At road-side stations, or where there are no works in the neighbourhood whence a supply can be obtained, the cheap and simple apparatus, manufactured by Messrs. Porter and Co., of Lincoln, may be advantageously used. At all terminal and terminal intermediate stations, there should be a siding under cover for engines in steam, and every facility should be provided for coking and watering.

Terminal intermediate and junction stations should have platforms for through passenger traffic, on both sides of the main line, to avoid the confusion which results from having them on one side only, as at Taunton, Reading, and Perth. At the latter place, although it is a junction station for the Inverness, the Perth and Dundee, the North British, the Scottish Central, and the Scottish North Eastern Railways, the whole of the traffic of thirty-two trains per day, each way, is worked upon one through line, causing a great amount of inconvenience, which might have been avoided by placing the station upon one of the roads, instead of midway between them as it now stands. There are, however, two docks, one at each end of the platform, for those trains which commence and finish their journey at that station. The utility of this arrangement, as enabling passengers by local trains to alight on the platform for through traffic, and *vice versâ*, has been already pointed out. It will prove a great accommodation also at these stations to have two through lines in the centre, and sorting sidings for the mineral and goods traffic. At all stations these two latter departments should, if possible, be distinct.

At roadside or intermediate stations, the best site for the booking-offices is of course on that side of the railway whence the greatest amount of traffic may be expected. If the station, however, be at a point where the line runs in a deep cutting, it is then judicious to place the offices over the line, which may be done by widening the road-bridge. The platforms are most conveniently arranged when the lower end of the one serving the up line is opposite the upper end of that for the down line. No platform should be shorter than the longest train; nor should it terminate abruptly, but with a slope. At these stations the company will find it their interest to provide a residence for the clerk in charge; he will be near at hand in case of emergency, and his remaining on the premises will afford greater security to property.

The next part of the subject to be considered is that of goods yards, wharves, and depôts. A terminal goods station may either be attached to and form part of the passenger-station, though distinct from it, or it may be placed at a distance, and enclosed within its own fencing. It is important to take advantage of water carriage, and to locate the station where the easiest access may be obtained. Ample space for vans and wagons should be provided in the yards and sheds, and also at the entrance gates and in the roadway, to prevent crowding, and to diminish the risk of accident. The platforms for arrival and for departure should be distinct, and of ample width, with an abundance of hydraulic crane power, to facilitate the loading, unloading, and sorting of goods; whilst the clerk's office should be so arranged as to allow of easy supervision. The lines and turn-tables should be so disposed, that the trains may be made up with facility and economy, and that the necessity for shunting with engines may be avoided as much as possible. In some small terminal stations, and at road-side stations, it is found convenient, and conducive to a saving of cost and of time in working, to place the goods shed close to the station, so as to enable the station-master to have ready access to this part of the traffic. In all cases the shed should be parallel to the line, that trains may be shunted into it, and the use of turn-tables be avoided. The goods sheds, and the various buildings connected with them, should be arranged to lock up when not used; by this means the expense of a watchman is rendered unnecessary, and safety from pilfering is greatly increased. This plan is adopted with excellent results on the South Devon and Cornwall Railways. The other requirements of goods stations will receive more detailed notice in the description of the plans which have been selected as illustrations of the subject.

The development of the railway system has necessitated that all important lines should be provided with three classes of establishments—for manufacturing, for maintaining, and for storing the rolling stock, at one or more points. At the first, the locomotive and carriage shops, all the construction and renewal of plant is performed; in the second, the running shops, small repairs, such as are required by daily wear and tear, are carried out; and the third, or engine and carriage sheds, are for receiving the rolling stock when not in use. Great care and forethought are required in the selection of suitable situations for these offices; for if any error be committed, a constant, increasing, and unproductive expenditure is certain to be incurred. The most eligible locality for the locomotive and carriage shops is where labour and materials can be most cheaply and readily procured. Considerable study should also be bestowed upon their arrangement, so as to allow of the economic application of labour in the conversion of the material. It is obviously a great evil so to design them, as to necessitate unremunerative handling and shifting. The raw material should enter at one end of the shop, and pass on through its successive stages and processes, till it comes out complete at the other end. It is advisable, in all cases, for the District Superintendent of the locomotive and rolling stock, to reside near the works, and to have them constantly under his supervision. Carriage running and repairing shops, when as close to the terminal stations as possible, are in the best position for avoiding waste of time, and wear and tear of stock. The disadvantage of placing them at a distance is exemplified by the Waterloo Station of the London and South Western Railway. The trains are made up at the terminus, where there is a small amount of standing-room, while the carriage sheds are at the Falcon Junction; in consequence of which nearly all the spare carriages have to be taken four miles, when emptied, and to be brought back again when required for service; and it is calculated that engines and empty carriages run in this way several hundred miles per week.

Engine and running sheds appear to be of three descriptions—rectangular, circular, and radial or fan-shaped. The circular shed is used by the Midland Railway Company, and the rectangular and radial by the Great Northern. (Plate 11.) The objections urged against the last are the length of line and the extent of ground occupied; but this is in a great degree obviated by placing the running shed in the centre, in front of the repairing shed, thus utilising what, without the running shed, would be a waste of space. Another objection is, that all the engines must pass over one pair of points; but this is not so serious as that of the single turn-table in the centre of the circular shed. In both cases, to guard against delay from accident, a few engines in steam should always be kept in covered sidings at the station. The accommodation afforded by the rectangular building in the centre of the fan is equal to that of the circular, though the area covered by the latter is nearly one-third more. There is no doubt, however, that the rectangular system requires a greater extent of permanent way; but this is partly compensated, by the less costly nature of the building. The semicircular shed, on the fan-shaped system, can easily be compared with the others; the only superiority it possesses over the circular is, that of having but a portion of the radius covered. On the other hand, it involves a great length of extra road from the turn-table, when one is used as at Battersea (Plate 12, Fig. 1); and should that get out of order, all the engines must remain in the shed until the defect be remedied. An engine shed should be lofty, well ventilated and lighted, and sufficiently spacious to allow the men to pass readily between the engines and the walls. Engine pits, properly paved, by the side of each line of rails in the shed, will afford free access to the machinery under the boiler when cleaning and repairs are needed. The best form for the bottom of the pits is convex; and the drainage should be from the sides, taking care so to construct the drains, that if any one pit should become choked, the working of those in any other would not be interrupted. For dropping and cleaning the fires, similar pits should be provided outside the shed, where the dirtier and rougher work can be performed. Plenty of water, with a good pressure, and accessible at suitable places by means of hydrants and stand-pipes, should be supplied, together with hose and conveniences for cleaning and washing the boilers. Lifting-shears, or overhead traversers, with powerful tackle, will be found of great service in every shed. By their aid an engine can be lifted and slung, so that the strain is distributed equally; they are therefore preferable to jacks, which concentrate the strain immediately over one point. The new shops at Nine Elms, of the London and South Western Railway, designed by Mr. Joseph Beattie (M. Inst. C.E.), and the engine sheds at the Bishop's Road Station of the Metropolitan Railway, by Mr. Fowler (President Inst. C.E.), are supplied with traversers worked by steam power. These effect a great saving of space. The employment of duplicate traversers, working from each end, to prevent delay in the case of a break-down, will, no doubt, ultimately be adopted. The coke furnace should serve for the largest number of engines with as little movement of the lighted fuel as possible. The waste heat can be utilised for drying the sand to be used in the locomotive boxes, and for heating the sheds during the winter months. The coke platforms and the water cranes should be close to the lines leading into, or out of the sheds, so as to be accessible without shunting; and the stores in general should be adjacent to the repairing and running sheds, and planned with a view to prevent any material being taken in or out, without passing under the notice of the storekeeper.

The different kinds of stations belonging to the railway system of this country, their requirements, and some of the principles involved in their construction, having now been briefly described, it is proposed to illustrate the subject by referring in detail to the following existing stations, which are considered to embody most of the points touched upon:—The Victoria Station at Pimlico, for the London, Chatham, and Dover, and the Great Western traffic, from the design of Mr. Fowler, President Inst. C.E.; the Victoria Station at Pimlico, for the London, Brighton, and South Coast, and Crystal Palace traffic, from the design of Mr. Jacomb Hood, M. Inst. C.E.; the London and North Western Railway terminus at Euston Square, by the late Mr. Robert Stephenson, M. Inst. C.E.; the New Street Station, Birmingham, belonging to the same Company, and the Stafford Station, also on the London and North Western Railway, both from the designs of Mr. William Baker, M. Inst. C.E.; the Newton Junction of the South Devon Railway, from the design of Mr. P. J. Margary, M. Inst. C.E.; the goods station of the Great Northern Railway, at King's Cross, from the design of Mr. Joseph Cubitt, V.P. Inst. C.E.; the London, Chatham, and Dover Railway workshops at Battersea, from the designs of Mr. J. Cubitt and Mr. F. T. Turner, M. Inst. C.E.; and the railway carriage factory and workshops of Messrs. Brown, Marshall, and Co., Birmingham, from the designs of Messrs. Marshall and Ross. For convenience of comparison, all the plans are reduced to one uniform scale of 100 feet to the inch; the appliances common to all the stations being denoted by the same letters of reference throughout, a list of which is appended (page 276).

At the Victoria Station of the London, Chatham, and Dover and the Great Western Railways, the booking-offices, &c. (at the entrance to which is a covered carriage-way), are on one side of the station. The waiting-rooms are conveniently placed near the booking-offices, and the refreshment-rooms are large and well appointed. The parcels traffic is satisfactorily provided for, the out-parcels, in-parcels, and left-luggage offices being very commodious. The lines running into the station are of mixed gauge; and three trains can be prepared to start at the same time. There are two departure platforms (one of which is worked double), and two arrival platforms, with a cab-road between. On one of them is the Customs-office, for the Continental traffic. Connected with the station are sidings for spare carriages, a water tank, a coke platform, and an engine turn-table. The cab-road has only one point of ingress and egress, an arrangement which is objectionable, from its tendency to cause confusion. The roof is in two spans, and the supporting columns are placed between two lines of rails.

At the West End Terminus of the London, Brighton, and South Coast Railway, at the same place, the booking-offices and waiting-rooms are placed at the end of the station, and at right angles to the lines of rail. There are separate offices, platforms, &c., for the Crystal Palace traffic, to prevent crowding. Between the arrival platforms is a cab-road, having a distinct entrance and exit.

At the Euston Station, Plate 10, Fig. 1, the booking-offices are placed on one side of the large entrance hall, from which access is gained to the two departure platforms. A glass roof shelters the entrance to the station. The New Street Station, Birmingham, Plate 10, Fig. 2, is terminal-intermediate;—intermediate for the London and North Western, and Midland Railways, and terminal for the Stour Valley line. It is in a cutting between two tunnels. The two main lines run through the centre of the station, and the platforms are approached by sidings, so that through trains are not stopped by the station traffic. The principal booking-offices are over the refreshment-rooms, and on a level with the bridge by which access is gained to all the platforms. The way is indicated by boards, at the top of each staircase leading from the bridge to the several platforms, where fingerposts are placed to point out the destination of the several trains. An iron and glass roof, of considerable height, covers the station in one span.

The Stafford Station, Plate 10, Fig. 3, recently erected, is terminal for the Trent Valley, and Shropshire Union trains, and intermediate for the London and North Western Railway. Two main lines run through the centre, the platforms being approached by sidings. There are docks and sidings for the arrival, departure, and marshalling of trains for the London, Birmingham, Trent Valley, and Shropshire Union lines. At the north end are the painting-shop, engine-house, and all the usual conveniences required at a terminal station. At a short distance from the passenger station are the goods station and the sorting sidings. These, it is believed, were first introduced by Mr. W. H. Barlow, M. Inst. C. E., on the Erewash Valley Railway, near Derby. When a mineral, or goods train arrives at Stafford, composed of trucks going to Birmingham, or to stations on the Stour Valley, or to the Shropshire Union lines, the trucks are detached and put into their respective sidings until a sufficient number is obtained to form a train. This arrangement saves time, and enables thirty-six goods trains to be despatched from this station in the course of twelve hours. There are in all five sidings, two on the up-side of the main line; but these are found insufficient to accommodate the traffic; two for the coal-trade of the town; and there is one to the cattle-wharf.

The Newton Junction Station, Plate 10^{A}, Fig. 1, is terminal-ntermediate for the South Devon Railway, and a junction for the branch to Torquay and Dartmouth. It is very conveniently arranged. The approach is by a single line of railway at one end; and there are three platforms—two for the main line traffic, and one for the Torquay and Dartmouth branch. Each platform is easily reached by means of a bridge over the rails. The principal offices are on the up-side; and there is a small waiting-room on the central, or Torquay platform. Near the station are the repairing-shops, engine-sheds, goods-warehouses, &c. The carriage repairing shops are supplied with a traverser, by which the carriages are deposited on a short rail connected with a large turn-table at the end, and are then turned on to any line, when required for use.

The goods station of the Great Northern Railway at King's Cross, Plate 11, comprises coal depôts and wharves, potato stores, engine sheds, repairing sheds, stores, stables, and all the necessary offices, buildings, and appliances required for the goods and mineral traffic of the Company. A portion of this site is used by the Midland Company, who have their goods warehouse and running shed on one side. The goods shed of the Great Northern Railway is placed at the south end, nearly in the centre of the station yard. There are fourteen lines of rails running into it; and there is a platform on each side for the receipt and despatch of goods. On the outside of the rails, but within the building, space is reserved for the vans engaged in collecting and distributing the goods. The outer line of rails on the east side of the platform is used for unloading the trucks with the inward goods; and that on the west side for loading the outward goods. The inner lines nearest to these are used for the arrival goods trains, for empty trucks, and for making up trains for departure. The trucks, after being unloaded, are taken, by means of turn-tables and cross-roads, to the departure side of the station, where the business of loading and despatching them is carried on. The platforms are commodious, and each have two rows of hydraulic cranes, of alternately one and two tons. The receiving-offices are on the platforms, but the general offices are adjacent to the main building. The stables are under the platforms; by which arrangement a great saving of space is effected. The granary is at the south end of the goods shed, through which it is approached by two lines running through the centre; two other lines, one on each side of these, being reserved for full trucks. When emptied, the trucks are removed by two lines, which run one on each outer side of the goods shed. The latter and the granary are supplied with water-communication through tunnels under the roads, to a basin on the south; and thence by the same means with the Regent's Canal, so that lighters can receive or discharge their freights directly under these buildings. On the west of the goods shed are the coal depôts and staiths; and a coal and a stone dock, also connected with the Regent's Canal. Adjoining, are numerous private wharves for bricks, &c. On the north are the engine, repairing, and carriage-sheds. There are eleven lines in the centre, at the extremity of the fan, in the repairing shed, with shops in the rear; seven lines on the south, in the locomotive painting-shed; and seven on the north in the carriage-shops. The running shed is placed in the centre of the fan, in front of the repairing shed, with which it communicates by through lines connected by means of a traverser. The potato-store and market occupy the eastern portion of the station, and are near the Midland goods shed. The whole is conveniently arranged, and the site is well chosen.

The locomotive workshops of the London, Chatham, and Dover Railway, Plate 12, Fig. 1, are situated near the Stewart's Lane station, on the Metropolitan extension of that line. The works proper are enclosed by a wall.* At the entrance from the railway, there is a building on the right, for the time-keeper and police. A single line connects the works with the main line, by means of points and crossings. Two parallel lines, running east and west, are connected with the several buildings by turn-tables. On the north of these lines is a range of buildings, containing the Engineer's offices, boiler-house, coal-store, grinding-shop, and turning-shop. On the south, under one roof, are the boiler-maker's shop and the lamp room. On the west is the erecting-shop, containing ten stalls on each side for engines, and a traverser which runs north and south. On the west of this building is a hooping and tyring shop, with a traverser connecting twenty lines near the north end of the carriage and wagon shop. Further west are the saw-mills; and near these, at the extreme west, the engine for working them, and also a drying house and a boiler house. On the south of the several buildings just enumerated are the stores. There are roads for spare trucks, &c., connected with the main line, and having a separate entrance. Adjoining the works, but not within the enclosure, are the repairing shops, and a semicircular running shed, struck with a radius of 150 feet, only the outside 50 feet being covered. Within this building are twenty-one stalls for engines with their tenders. The turn-table in the centre is not covered, nor the forty roads radiating from it, each of which is sufficient for an engine and tender. It is connected with the main line by three separate roads. At the back of this shed is a shop for running repairs, with smithy, engine and boiler house, and engineer's and foreman's offices. A line of rails connects the above shed with the works, through an engine weigh-house.

The Britannia Carriage Works of Messrs. Brown, Marshall, and Co., of Birmingham, Plate 12, Fig. 2, may be taken as successfully embodying the two great requirements of such premises, viz., suitability of site, and convenience of arrangement. The communication, by rail and water, is free and uninterrupted; for a level junction with the London and North Western line, with ample siding accommodation, beside large wharfage on the Stafford and Birmingham Canal, affords access both to London and Liverpool. Their position is also central in regard to the district from which the necessary materials are obtained, being close to the borders of the Staffordshire coal and iron fields.

On the left are two smiths' shops, parallel with the public road beyond. These are intended for the supply of iron-work only; this arrangement has proved advantageous, by obviating the necessity of interfering with the progress of the carriage work. To the right of the smiths' shops are the bolt shops and the fitting shops; in the former all bolts are forged and screwed, and plates bevelled. The saw-mill and log-mill adjoin; here all the woodwork is planed, tenoned, and mortised, before passing into the carriage and wagon shops. In each of the latter are eight lines of rails and a traverser communicating with the siding. The carriage painting shop is placed next the erecting shop, and communicates with it, but is sufficiently removed from the smiths' and the fitting shops to be free from dust or gases. It has four lines of rails, communicating with the traverser just mentioned; and has attached to it the paint stores and trimming-room. The carriage-body shop and wagon repairing shops, are provided with a traverser through the centre, and communicating with the siding. The general stores stand in front of the wagon shop. The building in the yard (A) is the shipping stores, where the packing and marking are completed. The packages and cases are run upon a tramway, to a crane placed by the inner siding.

The foregoing illustrations have reference only to systems and establishments now in undoubtedly successful working, and will, therefore, it is hoped be found useful and practical. It should be understood, however, that it is impossible to lay down rules which shall be applicable to all railway stations. The formation of the ground, the nature and extent of the traffic, the capital to be expended, and the views entertained by the Directors and the Traffic Manager, will inevitably modify the arrangements in each case. Some requirements, certainly, are common to all stations, while others are only exceptional; but even in those which are more or less indispensable, no absolute rule can be given. Much, therefore, must always be left to the skill and adaptive power of the Engineer. Yet, the Author would remark, in conclusion, that if in addition to the essential qualities of a station,—spaciousness, cleanliness, accessibility, and light,—the trains are frequent, the fares moderate, and even low, and if attention be paid to the comfort of the passengers, the results can scarcely fail to be satisfactory.

The Paper is illustrated by a series of diagrams, from which Plates 10, 10^{A}, 11, and 12 have been compiled.

APPENDIX.

REFERENCE INDEX TO THE PLATES.

A. P.	Arrival Platform.
B.	Bridge.
B. O.	Booking Office.
B. S.	Book Stall.
C.	Customs.
C. D.	Carriage Dock.
C. E.	Coffee Room.
C. O.	Cab Reporter's Office.
C. R.	Cloak Room.
C. R. D.	Cab Road.
C. S.	Carriage Shed.
C. S. P.	Coke Shed and Platform.
C. W.	Covered Way.
D.	Delivery and Enquiry Office.
D. P.	Departure Platform.
D. R.	Dining Room.
E. M.	Engine Men's Room.
E. O.	Engineer's Office.
E. R. S.	Engine Repairing Shop.
E. S.	Engine Shed.
F. P.	Foreman Porter's Office.
F. S.	Fitting Shop.
G.	Grease House.
G. R.	Guards' Room.
G. O.	Goods Offices.
G. W.	Goods Warehouse.
H. C.	Hydraulic Crane.
H. H.	Hydraulic Engine House.
H. W.	Hot Water Room.
I. P.	In Parcels.
I. R.	Inspector's Room.
K.	Kitchen.
L.	Luggage.
L. L.	Left Luggage.
L. O.	Lodge.
L. R.	Lamp Room.
L. W. R.	Ladies' Waiting Room.
O.	Offices.
O. P.	Out Parcels.
P.	Police.
P. O.	Parcels Office.
P. R.	Porters' Room.
P. S.	Painting Shop.
P. Y.	Pantry.
R.	Running Shed.
R. R.	Refreshment Room.
S.	Scullery.
S. B.	Signal Box.
S. C.	Spare Carriages.
S. M.	Station-Master's Office.
S. O.	Stores and Offices.
S. R.	Superintendent's Office.
S. S.	State Apartments.
S. S. B.	Stores Buildings.
S. T.	Stores Sheds.
T.	Telegraph.
T. C.	Crane.
T. F.	Traverser.
T. H.	Tank House.
T. O.	Ticket Office.
U.	Urinals.
W. C.	Water Crane.
W. R.	Waiting Room.

[Mr. R. J. Hood

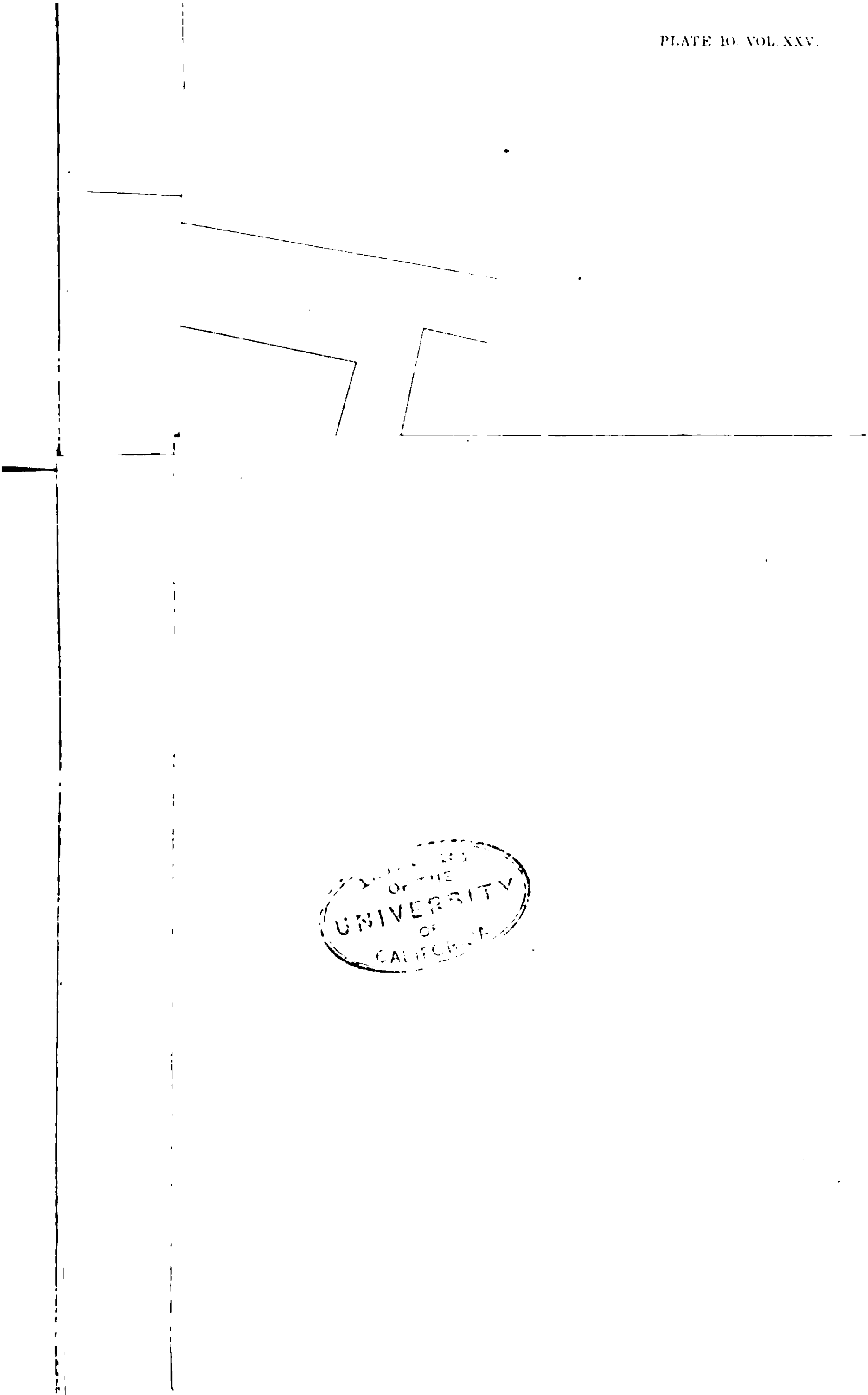

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PLATE 10A. VOL. XXV.

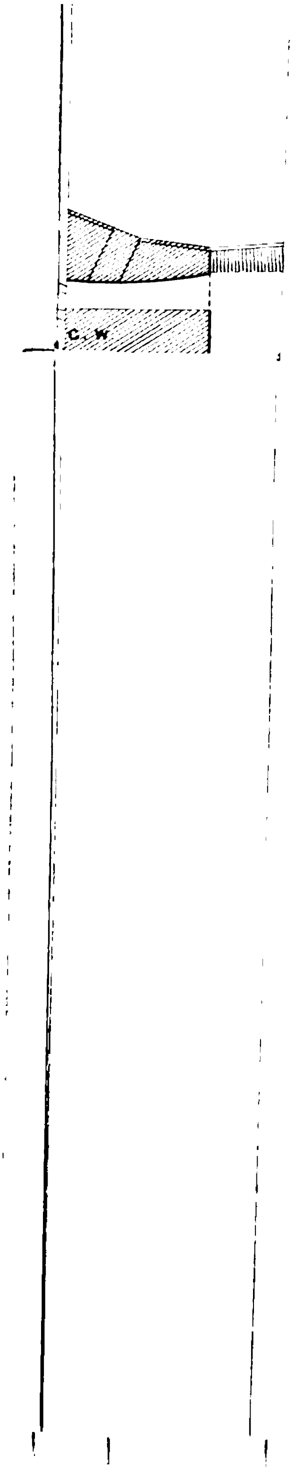

PLATE 10A. VOL. XXV.

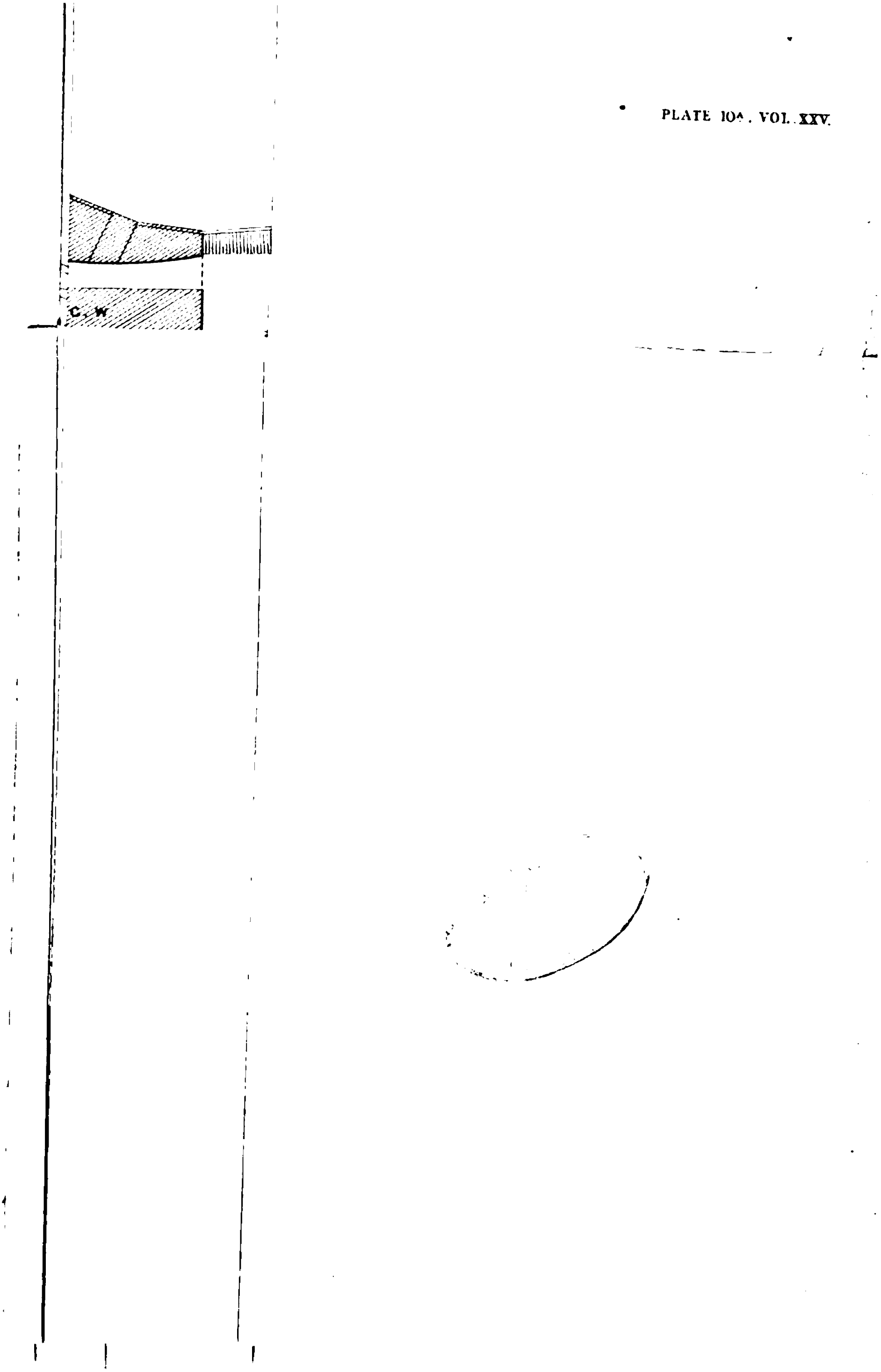

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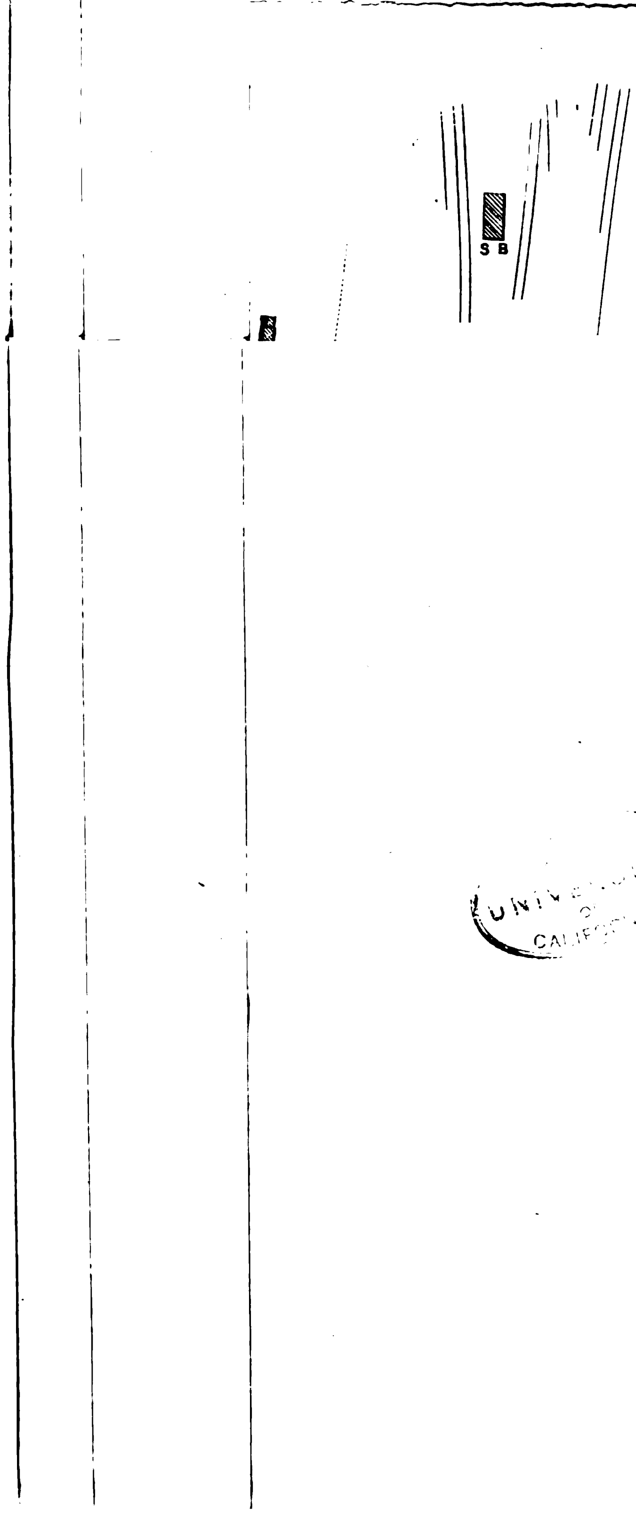
PLATE II VOL XXV.



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Mr. R. J. HOOD said, every one must so fully concur in the value of the Author's suggestions, that there was little room for comment or criticism. The question of the form and arrangement of locomotive sheds was important, and gave rise to a variety of opinions. With regard to circular or polygonal sheds, he considered that economy in space was the only advantage that could be urged in their favour. Wherever it was practicable, he thought that rectangular sheds of moderate length, with entrances at both ends, and as many lines of rails as possible, were the best. Station accommodation would necessarily depend upon situation, and the space at disposal, so that no general rules could be applicable to all circumstances. He would suggest that it would be useful to elicit opinions, as to the relative proportions between the length of platforms and the length of the trains. The length of the Brighton departure platforms at Victoria was twice, or three times the length of any ordinary trains that were started from them. The experience in that respect, however, had been satisfactory, and negatived the objections which had been raised, as to long platforms interfering with the working of the trains. He considered, in the case of the London, Chatham, and Dover portion of the same station, that there was a deficiency in length of platform as compared with the Brighton accommodation. Where trains were sent out at short intervals in different directions, it was a great convenience to be able to make up one train behind another, at times when business in the station was slack, so that when one train had left, the engine could come up for the next, and so on for the other trains following.

Mr. C. W. EBORALL remarked, that experience had shown him the importance of having ample and convenient repairing sheds other than those at the principal works. It frequently happened that rolling stock, when requiring trifling repairs, had to be sent to the main depôt; the erection of subsidiary workshops at other stations would save this useless running, and be an economy to the revenue of the Company. On the South Eastern Railway, the works at the large stations were not sufficiently commodious for repairing the rolling stock which came to London, and it was often necessary to send vehicles to Ashford; this involved not only superfluous expense in running, but an additional delay in recovering the service of the stock. With reference to metropolitan stations, where the value of land was very high, the disposition of the plans must, of course, be subject to restrictions as to space, &c. At the Victoria Station, Pimlico, the arrangements of the Brighton Company seemed better than those of the London, Chatham, and Dover; and he thought the latter Company would have done wisely, if they had placed platforms and sidings on the land now occupied by offices.

Mr. J. S. FORBES quite agreed that the offices and platform arrangements of the Brighton Company at the Victoria Station were more convenient for the purposes of a terminal station than those of the London, Chatham, and Dover Company. The plan of having, in a terminal station, the offices, waiting-rooms, and accommodation for dealing with passengers' baggage, parcels, &c., at the end of the building, and of affording ready access to every platform, was preferable to that of providing similar accommodation parallel to the platforms. This latter plan, in addition to a certain amount of inconvenience to the public, involved greater cost in working the station. The stations at Denmark Hill and the Crystal Palace were arranged upon a system well adapted for intermediate stations of that character. It was said that, in laying out stations, Engineers must be governed by considerations of cost, but he thought great after-expense was saved by a judicious first outlay. The advantages of the transverse arrangement applied equally well to terminal or to intermediate stations, since, at intermediate stations, if the level of the rails and platforms was below that of the adjacent streets, that system could be conveniently arranged, as at the new Metropolitan Station at Farringdon Street, by carrying the transverse gangways over the rails, and giving easy access to different platforms. On the other hand, if the rails and platforms were on a viaduct, it could be equally well applied, by carrying the access and accommodation for passengers beneath the railway, as at the Ludgate Hill Station. The great point was, to get facility of access from the offices to every platform, and to pass as much of the traffic as possible through one or two offices. This was well illustrated at the two stations at Victoria. Passengers to Hastings, or Brighton, or Croydon could be perfectly well accommodated through one set of offices, including different booking windows, and one set of waiting-rooms and refreshment-rooms ; and on passing from the offices, or waiting-rooms, a direction board placed over the entrance to each platform would at once indicate the way to the various trains. The control of a station under such a plan was very easy, and it afforded a better opportunity of putting the platforms to different uses, as at the old station at Farringdon Street, where with a small force of men the stream of traffic was easily diverted from one entrance to another when necessary. This it was impossible to do with the London, Chatham, and Dover arrangements at Victoria, and in consequence, it was necessary to combine the two systems, and the Company were obliged to open distinct booking-offices for the short traffic, in order to get the passengers properly separated. But there was one thing connected with the working of a metropolitan station of even more importance than the internal arrangements, at least, as far as concerned public convenience—and that was, proper and sufficient railway access; because ingenuity might be wasted in planning a station, unless a good means of getting trains in and out of it were at the same time provided. The complicated business of a large railway was seriously interfered with, when the whole of the traffic was concentrated upon two lines of rails at a station. He had found that to be the case at Victoria Station, and to obviate the difficulties thus created, considerable expense had been incurred in additional works. Many of the points referred to depended upon the nature of the traffic. With respect to trains to Brighton, Dover, and long distances at intervals of time, it was desirable and possible to marshal two, or three trains at the same platform, but with that method there was the risk of passengers getting into wrong carriages. For a short and frequent metropolitan traffic quite another set of circumstances obtained. In that case the great object was to keep the rolling stock moving to and fro, like a pendulum: and the platform should be so designed, that trains on coming in could be discharged from one side, and reloaded from the other. That accorded with the public convenience, and was economical in regard to space and labour. In metropolitan stations it was difficult to meet these contingencies. The making up of several trains at the same platform was desirable in the case of long traffic, but a shorter platform with lines on either side was, in his opinion, preferable in the other instance, involving as it did the necessity of a small 'lay-by' for the engine to come up to the train. That was what he should like to see combined in stations like Victoria and Ludgate. He thought a useful lesson might be learnt from the railways in Germany. In that country, Engineers had been in the habit of taking much more space for stations than had been done in England, by which they not only diminished the eventual cost, but added considerably to the facilities of working. There was one other question he should like to hear discussed:—the use of stations in this country was a good deal limited by the adoption of high platforms, and he mentioned the subject in order to elicit opinions upon it. The decision of Engineers on the Continent had been given against the adoption of platforms; on the ground that it was impossible, when the height of them was considerably above the level of the rails, to conduct the traffic with the same facility as if there were no platforms. It might be worthy of consideration whether, at these large terminal (and also at intermediate stations, with express trains running through them), platforms should be retained, or if retained, whether their height should not be so inconsiderable as to admit of the greatest possible circulation. It was, however, merely in relation to large terminal stations, that he had brought the subject forward, and not as generally advocating low platforms.

Mr. T. E. HARRISON said, his experience went to prove that the accommodation outside a station was as important as that of the interior; and he had adopted, as a uniform principle, that only half of what was essential for working a station was completed, unless provision had been made for fully as many yards of standage beyond the point where the sidings met, as were provided for the station itself. It appeared that the great defect of the Crystal Palace and the Victoria termini was in the want of proper means for getting rid of the trains after their arrival at the platforms. On the subject of low platforms, he thought that if facilities were given for crossing the lines, the result would be frequent and serious accidents to the passengers. In the earlier stations, thirty years ago, there were no platforms at all; in other cases, about the same period, their height was not more than 6 inches above the level of the line. At the Newcastle Central Station, when originally constructed, the platforms were only 15 inches above the level of the rails; but at the present moment he was lowering the road, so as to give the platform a height of 3 feet above the rails. With regard to the objections which had been urged against the employment of circular engine sheds, the great question was the nature of the turn-tables used. He had adopted wrought-iron tables rotating on a pivot, on which engines weighing 40 tons were turned with the greatest ease by the fireman; and he had not known an instance of one of those machines getting out of order during a period of several years. He had constructed one engine shed capable of containing ninety engines: there were five tables with lines radiating from them, each set of lines being sufficient to accommodate eighteen engines, all being connected with other lines leading to the station, and the whole comprised in one building. Plate 12, Fig. 3. No rectangular shed could be constructed to hold so large a number of engines.

Mr. VIGNOLES remarked, with reference to the proposal for introducing low platforms, that the French had carried out this system to a great extent; and it had also been adopted in Belgium and Germany. Anybody, however, who had stopped at the intermediate stations of Malines, near Brussels, would be aware of the great extent of station ground, there covered with numerous lines of railway, among which passengers had to look for their carriages at great personal risk; and nothing was more inconvenient than the ascent to and descent from the carriages. In Spain he had resolutely insisted upon having platforms. He knew that in the early days of railways in England, platforms were scarcely thought of; but the convenience of them had since been universally appreciated.

Mr. SEYMOUR CLARKE said, the conclusion at which he had arrived, after thirty years' practical experience was, that no general rule could be laid down with respect to the plans and arrangements of railway stations. What would be good for the terminal station of a long line, with a large and heavy through traffic, including a considerable amount of passengers, luggage, &c., would not be adapted for a short suburban traffic, with very frequent trains, carrying large numbers of passengers, with little or no luggage, and whose principal object was to be conveyed with the greatest possible regularity and despatch. Apparently the best way of laying out a station for the purposes of a long line traffic, was to place the offices at the side of the platform; for, a train, when starting from London for the north, to Liverpool, or Scotland was so extensive, and the passengers had to locate themselves in so many different places according to their destination, that they wanted space over which to disperse themselves, in order to see that their luggage was properly cared for, and to find the carriages in which they were to commence and finish their journey; and for those purposes the lateral arrangement was the most conducive to the proper working of the traffic. His own experience in these matters had been latterly in connection with the Great Northern Railway, and he was satisfied it would have been a great mistake, if in laying out the station at King's Cross, the offices had been placed at the end of the platforms; at the same time, he admitted that if the station had been designed for a metropolitan and suburban traffic only, the offices should have been in a different position; for metropolitan or suburban passengers did not care into which carriage they got, because they knew that the train would proceed to its destination, without any of the carriages being detached in the course of the journey. He regarded the distribution of the luggage also as a very important element, and on that ground, as well as many others, he was in favour of booking-offices parallel with the platform for long traffic. Besides the instance of King's Cross, he might mention the New Leeds station, which was used for both long and short traffic connected with the West Riding of Yorkshire, and which might be called a metropolitan traffic. The offices were originally placed alongside the platform for the purposes of long traffic, but it was found that the short traffic preponderated, and the station was altered by the booking-offices being placed at the end of the platform, in order to adapt them to the purposes most required by the greatest number, viz., passengers going in the morning without luggage, and returning in the evening. In fact the two descriptions of traffic could not be conveniently worked from the same platform; and the best possible arrangement, both for the public and the company, was, that the long traffic should have an area right and left where the passengers could disperse on a long platform; but for the convenience of the short traffic, the booking-offices should be at the end of the station.

With respect to the laying out of goods stations, he did not think the best mode had yet been arrived at, because the increase of business had been such, that not one of them had been made large enough to meet the yearly exigencies, especially at the metropolitan stations. He was forcibly reminded of this fact when he looked at the plan of the King's Cross Station, which, as it now existed, was not the result of a well-considered scheme as a whole, but had been carried out from time to time. The original scheme of the late Sir William Cubitt comprehended a large goods warehouse and one or two of the coal depôts, but scarcely half of the area now appropriated to station purposes; and it must be added, that the whole space between the circular engine-house and the North London Railway was at present filled with lines of rails, and that there was no further space to rely upon, except by removing the engine department further north. This would bear out the statement, that the metropolitan stations were not yet large enough to meet the wants of the growing traffic. The station at King's Cross was, two or three years ago, used not only by the Great Northern, but by the Midland Company. The whole space — which included one of the largest potato markets in London—was now fully occupied by the Great Northern Company alone; but even that space was insufficient. Then the metropolis was increasing so much in every direction, that before long King's Cross, St. Pancras, and Euston Square would no longer be outlying places, but would form the centre of London; and therefore any piece of land which the companies could obtain in the locality of their termini should be secured while free from building. This year the Great Northern Company applied to Parliament for powers to acquire several acres of land adjoining the Holloway Road, in order to provide sidings for coal and goods trains, with a view to making a depôt in which they could place the trains on arrival, and thus confine the goods and coal departments for sale or delivery to the consignees. The Midland Company were carrying out a similar plan in the direction of Kilburn. Those facts tended to show, that the spaces in London were not nearly large enough, and that it was good policy on the part of the companies to secure land some distance, yet not too far, out of London, which could at present be obtained at reasonable prices.

With regard to the comparative utility of turn-tables and traversers at passenger and goods stations, both those contrivances were necessary, especially in metropolitan stations. The moving of carriages from one line to another was admirably effected by means of traversers; but the latter were not applicable to horse-boxes and trucks which had to be moved half, or wholly round; in such cases turn-tables must be employed. The traversing apparatus was economical as regarded space, occupying less room than was required for the swinging round of a number of carriages. He thought, however, in most cases, that neither contrivance could be wholly dispensed with. With respect to the goods traffic, the great object was to have a train of the necessary number of wagons parallel to the platform, at which the goods were discharged from the collecting vans, so that the packages, boxes, or bales might be taken direct to the wagons which were to carry them. In the case of miscellaneous goods, which would not justify the running of special trucks, there should be what were called trans-shipping wagons, in which such goods could be placed and sent away by the trains calling at intermediate stations.

Mr. GEORGE FINDLAY, in allusion to the inconvenience, said to be felt at the South Eastern terminus, in having to send carriages from that station to the central workshops at Ashford for slight repairs, said he hardly supposed that it was contemplated having large workshops in the vicinity of London, but he thought the case could be met, if small workshops were erected for such purposes at the metropolitan and other large stations. There was another point, as to the arrangement of passenger stations, upon which an opinion had been expressed, that it was desirable, as far as possible, to have those stations either over or under the railway. For metropolitan traffic that might be convenient, but there were many cases where, of necessity, the station must be placed parallel and level with the line of rails, and then the question arose, as to the best and safest mode of crossing from one side of the railway to the other. In some places this was done by a bridge over, and in others by a vaulted archway under the railway, and, as far as his experience went, the archway under the line was preferable.

With regard to the relative length of platforms, that must vary according to the circumstances of the traffic. In the station at Stafford the platform was capable of accommodating a train of thirty carriages, and was about 600 feet in length; but while a platform of that extent was necessary for a large station like Stafford, one-half that length would be more convenient for a branch or metropolitan traffic. It had been doubted whether it was desirable to have platforms at all; but, he thought, the general opinion was, that platforms were not only essential for the safety, but also for the economical and proper working of a station. After mature consideration by the officers of the London and North Western Railway, as to what was the proper height of platform—a subject which had been much discussed—it was determined that 1 foot 9 inches was the height at which all platforms rebuilt, or building at their stations should be constructed.

Much stress had been laid, but not too much, on the immense growth of the goods traffic of the country during the last ten or fifteen years, and there could be but one opinion as to the necessity of providing a large amount of accommodation outside the great centres of population. The London and North Western Company had done this at Willesden, which would practically be the London terminus for the goods trains, whence the goods would be despatched by a series of short trains to the various metropolitan stations with which that line was in connection. A similar plan had been pursued at Birmingham, Wolverhampton, Liverpool, and at the two stations in Manchester. He was convinced, that the growth of the traffic would continue to be as great as it had hitherto been, and that the large amount of accommodation now provided could not be beyond what was required. The plan of the London and North Western goods shed at Camden, Plate 10^A, Fig. 3, had received a great amount of consideration from the manager and the other officers of the Company. He believed a plan embodying the same elements of construction had been carried out on the Lancashire and Yorkshire Railway, at Oldham Road. The lines of rails ran into a transverse platform at the end, and the wagons were worked into the station and out of it, by capstans, the motive power being hydraulic. There were also cranes of a power varying from 2 tons to 5 tons, the larger being worked by hydraulic, and the smaller by manual power. The total number of wagons which this shed was capable of holding was about 135, and in an ordinary night's work from seven hundred to eight hundred wagons, containing about 1,500 tons of goods, were loaded and sent away. Underneath were vaults, extending the whole area of the shed, for the storing of Burton ale; and it was proposed to lower the wagons into those vaults by a hydraulic lift, that the barrels might be disposed in the way which the brewers thought best. The arrangement for unloading the vans and carts was found to be most convenient, and he might state, that the result was a saving of nine hundred wagons per month, while the same amount of traffic was carried on.

Mr. ALLPORT thought that there was great difficulty in deciding upon the best mode of laying out a station; and in London, where both long and short traffic came into the same station, the difficulty was much increased. There was no doubt that for the long traffic the offices and waiting-rooms should be at the side, where the passengers could at once proceed from those places to the carriages. He thought, where it could be avoided, there should not be two sets of booking-offices at the same station. That system led to considerable confusion, passengers arriving at the last moment went to the wrong office; and it was desirable to obviate that as far as possible. In the new station to be erected by the Midland Company in the Euston Road (Plate 10A, Fig. 2), from the design of Mr. W. H. Barlow, M. Inst. C.E., in anticipation of a large suburban traffic to the districts of St. Albans and Luton, and also of long trains to and from the North, the booking-offices were so placed as to accommodate both descriptions of traffic. The portion which was designed at present for waiting-rooms could, in case it was necessary, be made available for a second booking-office, and the building would be carried out with that view, so as to give convenient access from the New Road to both. In the designing of this station the object had been to get as many platforms as possible. He believed that one of the great mistakes was not having sufficient platform room for the despatch of passengers. A large hotel would be erected near to and over the station, with means of access to it similar to those which existed at Paddington. The length of each platform would be about 700 feet and the width 30 feet. It would be a peculiarity of this building, that the roof would be in a single span of 240 feet apparently without any tie-rods. The whole of the station would be vaulted underneath, comprising about four acres, and the girders carrying the rails and platform would act as tie-rods to the principals. Those vaults were intended to be chiefly appropriated to the storing of Burton ale; and a further storage, to the extent of several acres, had been provided at the St. Pancras goods station. With regard to the latter station, two platforms were placed, one on either side, with a considerable number of lines between them, together with cart roads, so that carts and vans could go alongside the railway trucks without inconvenience. For light goods there was a central shed over the warehouse. The warehouse was about 300 feet long and 300 feet wide, and before it had been opened twelve months it was found necessary to make arrangements for doubling the size of it; and although there were hydraulic cranes and capstans, with every modern appliance, yet the growth of the traffic was such, that he had no doubt before another five years elapsed further enlargement would be required. The Company had bought and applied for powers to purchase about 200 acres, and altogether would have about 300 acres of land near London for their ultimate purposes; but he was convinced, in a few years that would be found insufficient. The necessity of providing sufficient land in the neighbourhood of London could not, therefore, be too much impressed upon railway companies. He thought it was a great mistake, where land was so valuable as it was in London, to place the engine-sheds close to the passenger and goods stations. It would be better to take the engines out a few miles, where land was cheaper, than fill up valuable space which would be better occupied for the purposes of goods and passengers. With regard to turn-tables and traversers, he thought the fewer of the former that were put down the better, being inconvenient in a passenger station and interfering with the platform, and on that account being even dangerous. He would, as far as possible, avoid them: traversers were more convenient, and more easily manipulated.

Mr. J. S. **Valentine** remarked, that no mention had yet been made of a class of station in which both the up and the down trains drew up to the same platform, as at the New Cambridge station. He thought this arrangement was not so convenient as that with double platforms, and perhaps the only plea that could be urged in its favour was the convenience to aged and infirm passengers in avoiding long flights of steps for the purpose of passing over or under the railway; but the great length which was necessary with a single platform was annoying to passengers in getting to the refreshment and retiring rooms, and in looking after luggage, especially where the train was drawn up at the extreme end. With regard to the abandonment of platforms altogether, he thought it would be exceedingly inconvenient even to lower the platforms, and he believed the tendency of late years had been to raise them rather than otherwise; therefore he was somewhat surprised at the statement that the London and North Western Company had adopted the height of only 20 inches, looking to the fact that the height of the platforms had been generally raised. He knew that the Inspecting Officers of the Board of Trade were very decided in their views, with regard to having platforms at all stations where passenger trains stopped. He was about to open a short line in a thinly-populated district, with the probability of only a small passenger-traffic, and at the stations where it was intended that trains should cross (it being only a single line), the inspecting officer insisted upon having a platform to the siding, although it was not intended that the passengers should alight there; therefore even if Engineers in this country might be disposed to do away with platforms, they would meet with opposition to the carrying out of their views from that quarter.

Mr. **Allport** added, that after much consideration the officers of the Midland Railway had decided upon 2 feet as the best height of platform. Single-sided platforms, at intermediate stations were, he thought, attended with great risk. On the Midland line such a station existed at Leicester, and had been altered to a double-sided station.

Mr. R. P. **Brereton** said, that the Engineers on the Continent had not universally abandoned station platforms; those on the Hanoverian lines were high, and it was the same in Tuscany, at the stations of the Maria Antonia Railway. He was not aware that any recent alteration had been made in that respect, or that the advantages and disadvantages of platforms generally had been discussed by Engineers abroad. In this country, about twenty-eight years ago, platforms were put up by Mr. Brunel at the Great Western stations; those were all high, and continued so for about ten years. At that period economical tendencies set in, and it was considered that the Company were extravagant in the luxurious accommodation afforded by their platforms, and that there were objections attending them. An investigation took place to ascertain whether the advantages were commensurate with the increased cost which the adoption of them involved. It ended in the decision that the erection of high platforms should be discontinued; that was in 1849. There were the South Wales, and the Birmingham and Oxford lines still to be constructed, and on both those lines low platforms were adopted. About two years after, reports were prevalent, that there were more accidents with the latter than with the former. Instructions were therefore issued to the superintendents of stations to furnish returns as to the number of casualties that had occurred, and the result showed, that the preponderance of accidents to the extent of broken limbs, &c. was at the platforms of 1 foot 3 inches, as compared with those where the height was 2 feet 9 inches, and that led to the abandonment of the low platform system. The alteration was carried out, and platforms were constructed on the South Wales, and on the Birmingham and Oxford lines. In some cases compensations for accidents at the low platforms were paid by the Company. In respect of economy, no doubt there was some advantage in low platforms, especially where the station was on a viaduct, as the increased height added to the cost of road approaches, &c.; but notwithstanding that, the Great Western Company returned to the use of high platforms.

Mr. GEORGE BERKLEY observed, that platforms ought to be uniform in height. At Preston the height was about 6 inches: at other stations on the same line of railway it was 2 feet: this variation was inconvenient when travelling in the dark. It was important that outside the station itself, there should be such arrangements as would admit of moving the trains from the arrival lines to intermediate, or departure lines · by locomotive power without crossing, or in any way obstructing the running lines; and thus, as much as possible, to avoid the use of manual labour and of machinery within the station. At the Great Western Station, a train on arriving at the platform was taken away by an engine, and placed upon one of eight or nine intermediate lines. The trains were sorted and shunted by the pilot-engine ready for their next departure. The lines so used should be free from, and not interfere with, the running lines. That was not at present entirely the case either at the Great Western, or the Great Northern Stations, where the system of making up trains was alike; at each, locomotive power was used for removing the trains and putting them into a fresh place, but at both the error was committed of making the sorting lines converge into two lines only, whereas, there should be one more line of 200 yards or 300 yards, along which the trains could be propelled, without crossing either of the main lines, and without the necessity for signals. The next point he would refer to was, that there should be as little machinery in a station as possible. Comparing the Great Western and Great Northern stations, it would be found, that at the former there were many costly pieces of machinery, which were unused. At the Great Northern Station this work was executed by Dunn's traversers, and a few turn-tables, auxiliary of the simplest means of sorting the trains, viz., by the power always at hand, the locomotive engine. It was impossible to lay down any rule to determine the best position of the booking-offices in all cases, but the access to them from the road should be easy, and the space between the booking-offices and the trains should be as short and unobstructed as possible. If the platform was very long, as at the Great Northern Station, the best situation was in the centre of that length rather than at either end, while at Fenchurch Street where there were five short platforms, the booking-offices were better at the end, the trains at these platforms being more easily approached than by the lateral arrangement. Generally, for suburban traffic, with short platforms, and where the distance to be travelled was short, the end offices were the most convenient, whilst with long platforms the booking-offices were better in the centre. He considered the best form of engine shed to be the rectangular, open at both ends. This had the merit of being able to be worked by locomotive power, of reducing to a minimum the use of manual labour and of turn-tables, and of facilitating the employment of lifting apparatus for examining the parts of the engine.

Mr. SEYMOUR CLARKE remarked, that the plan of the King's Cross Station went far to coincide with the ideas just expressed. The station was so laid out that the shunting of the carriages after a train arrived could be performed by the locomotive engine. It was true, the great defect of the station was that the lines converged too soon, but that was the result of want of space between the New Road and the Regent's Canal. A somewhat similar evil was about to be remedied as to the goods space, by doubling the tunnel; for this purpose application had been made to Parliament, and no doubt the same plan would be pursued with regard to the passenger station, viz., to tunnel under the canal. With regard to the original plan of the goods station, it was one of some years' date, and the arrangements were not the same as now existed. The system which Mr. Berkley advocated was carried out already in the goods department, and all the wagons could be marshalled and shunted without interfering with the main lines. The one-sided passenger stations, which had been referred to, were not, in his conviction, to be recommended for imitation. The Cambridge Station was a bad example of its class, because one important thing in a one-sided station where there was a long narrow platform was to have it as clear as possible, and in that instance about 15 per cent. of the whole width was taken up by the double row of wooden columns.

Mr. CAWKWELL said, the height of platform on the London and North Western Railway was that which was considered most convenient under general circumstances. There were, of course, exceptions; there were advantages in having high platforms at terminal stations, as at Euston, where luggage was carried on the roofs of the carriages: and there were also advantages in having lower platforms where there was no bridge, and consequently where the line had to be crossed to get from one platform to another. The position of the offices mainly depended upon the land which the Engineers had to work upon. If the shape was long and narrow, there must necessarily be a long platform and long sidings, and then the offices were better at the side. If broad and short, then the most convenient plan was to place the offices at the end, with a number of platforms. On the whole, the arrangement of offices at the end was the best; for short traffic it was admitted to be so. He knew many stations so constructed, and with a large traffic of both kinds, and those were worked in a more satisfactory manner than could have been effected with side offices: but their position was mainly influenced by the form of the ground. At road-side stations, it was of course impracticable to have end offices. With regard to goods warehouses, the remarks that had been made applied principally to terminal stations. No doubt the arrangement of the warehouses was of great importance, for there was no item more expensive to a Company than the cost of handling goods. The warehouse at Camden (Plate 10^{A}, Fig. 3), he believed, was one of the most convenient in England for working a large traffic: it was capable of containing 135 wagons at a time. There was a broad platform at the end of the warehouse, at which the vans were drawn up and the goods taken out, and conveyed in trucks to that part of one of the loading platforms where the railway wagons stood; each wagon having its allotted place indicated on a legibly painted board. At various parts of the platform, weighing-machines were placed, from which the goods were invoiced and loaded. By that means there was less chance of goods getting astray, than on the old plan. As had already been stated, the system worked so admirably as to have effected a saving of

900 wagons in the course of a month, although carrying an equal amount of traffic. There were other places to which that plan would not be applicable: for much depended upon whether the station was used chiefly for outward, or for inward traffic. At some the whole was roofed, and made a warehouse, as at the Waterloo Station at Liverpool, where from a higher stage or platform than was usual, goods were lowered into the trucks, either by cranes, or by hand. The arrangement was suitable to the locality, and was convenient for that particular kind of traffic, but not for all situations. It was impossible to establish any universal rule. All depended upon the position of the station, the land to be worked upon, and the nature of the traffic to be accommodated.

Mr. HAWKSHAW, Past-President, said, it seemed to have been nearly overlooked, that the shape of stations was seldom a matter of choice, but generally of necessity. Sometimes a station was to be constructed in a situation bounded by streets and buildings, often upon a site the shape of which was bad, yet the best that could be procured, and the plans must accord with that site. It was not as though Engineers had always a large open space like Salisbury Plain to deal with, and had no other task than to design the most perfect station on the most perfect principles, and of unlimited size. Nothing could be more contrary to the actual state of the case. He had been making stations during thirty years, and he had been compelled to construct many which, he thought, were neither so convenient, nor of so good a shape as he could have wished; but which had to be fitted to the only piece of ground that was available for the purpose. It was very difficult to define general principles on which stations should be laid out. The Paper had elicited the views of those who had great experience on the subject, but it was somewhat like a Paper upon the best form of dwelling-houses, and any discussion upon it must necessarily be wide, and rather vague; if the size, proportions, and arrangements of dwelling-houses were to be discussed, it would be necessary to settle first what were the conveniences required by the persons who were to inhabit them, and what were the means and capabilities for carrying out their views. It was not merely a question of ground with regard to stations, but also of cost and other things. First, there was the length of platforms. All that could be said was, that that must be governed by the length of the trains. Then there was the question of the height of platforms. Some preferred 2 feet 9 inches; others, 2 feet 6 inches; while on the London and North Western line, the standard of 1 foot 9 inches had been adopted. About that height, he thought, was sufficient; but even there again there could be no established rule. He knew many stations, and so did other Members present, where it would be inconvenient if all the platforms were made of that height. A very pertinent question had been asked, "How was it foreign Engineers adopted, as a rule, very low platforms, while English Engineers favoured high ones?" He had been struck with the same thing himself, and he had come to the conclusion at one time that it was chiefly on the score of economy. It was known that abroad, it was not usual to spend so much money on railways as was done in this country; but yet those low platforms would be found in stations of the most magnificent character, where it was not to be supposed that the question of expense had led to their adoption. One reason might be, that on the Continent, luggage was not put on the tops of the carriages; and it had been observed, that "high platforms were useful at terminal stations, where luggage had to be put on the roofs of the carriages."

Conflicting opinions had been expressed on the subject of booking-offices. Some preferred that the offices should be at the side; others, at the end. In the case of the St. Pancras Station, neither the one nor the other plan had been adopted; the offices were placed at the corner. The objection to placing the offices at the end of the station, on account of the increased distance, he thought had but little force. At most metropolitan stations, it would be found, that passengers would have about the same distance to walk, whether the booking-offices were at the end, or at the side of the station. If, as was at present the case at King's Cross, all the trains could be sent from one departure platform, the offices might safely be placed at the side; if otherwise, it would be a mistake to do so; and he was persuaded, that where the increase of trains would call for a greater number of departure platforms, it was better to put them at the end.

Mr. Gregory, V.P., suggested that a Paper on the subject of large workshops in connection with railways would be a valuable supplement to this communication.

February 20, 1866.

CHARLES HUTTON GREGORY, Vice-President,
in the Chair.

The discussion upon the Paper, No. 1,137, "On the Design and Arrangement of Railway Stations, &c.," was continued throughout the Meeting, to the exclusion of any other subject.

February 27, 1866.

JOHN FOWLER, President,
in the Chair.

No. 1,155.—"The Hydraulic Lift Graving Dock."[1] By Edwin Clark, M. Inst. C.E.

The advantages possessed by this system of docking vessels, having now been practically demonstrated by long experience at the Works of the Thames Graving Dock Company, in the Victoria Docks, and as other docks on this system are in course of preparation, the Author has thought that a detailed description would form a useful record on the Minutes of the Institution. The history of the invention dates as far back as the year 1857. At that time, the Victoria Docks were just completed, and it was part of the Engineer's original plan to construct a graving dock as an adjunct to that establishment. Plans were accordingly prepared for an ordinary dock, to be lined with brick, and to be emptied in the usual manner by tidal action and pumping. The estimated cost of the dock was £60,000. The Engineer—Mr. G. P. Bidder—who, in designing these works, had already introduced many important modifications with a view to economy, was anxious to adopt some cheaper system for docking vessels, of that large class for which these docks were laid out. Among other projects, the feasibility of lining a dock with concrete, timber, or with cast or wrought iron plates, was discussed. Mr. Stephenson suggested a closed pontoon dock, in which the horizontal position and the stability of the pontoon were to be maintained, by an arrangement of struts and braces attached to the ground, and forming a parallel motion. The necessary dimensions of these struts proved, however, to be so great, on account of their excessive length, and the great strain to which, in certain positions, they would be subject, that this arrangement, as well as other mechanical contrivances for securing stability with a submerged pontoon, was abandoned. A similar plan has since been carried out in the London Docks, where a dock on this principle was erected about two years ago. On the first attempt, however, to exhibit its action, fortunately without any vessel upon it, the pontoon filled and sank in about 22 feet of water. Some of the rods of the parallel gearing beneath having given way, and pierced through the bottom of the pontoon, it was found impossible to raise it again by pumping out the water; and it remains to this day, at the bottom of the London Docks.

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[1] The discussion upon this Paper extended over portions of four evenings, but an abstract of the whole is given consecutively.

Mr. Bidder, finding that no economy could be effected by any modifications of the ordinary dock, turned his attention to a floating dock; and with a view to preparing the necessary plans, requested the Author to visit the principal dockyards in England, and on the Continent, and to make himself generally acquainted with the various systems then in use.

The Author accordingly gave considerable attention to the subject, and, in conjunction with Mr. Stephenson and Mr. Bidder, various schemes for floating docks were discussed. All were found to be more or less objectionable; partly, from the difficulty of designing such large floating structures with sufficient rigidity to preserve their form under very variable strains, and to insure that stability of flotation which was wanting in all floating docks then in use; and partly, from their enormous cost. At this juncture, it occurred to the Author, who, under the direction of Mr. Robert Stephenson, had lately designed the machinery, and superintended the raising of the tubes of the Britannia and Conway tubular bridges, that a similar process might, with advantage, be applied to the docking of a vessel. The problem was simply to raise a given weight to a moderate height, in the most rapid and economical manner, and there appeared no reason why a vessel should not be dealt with in the same manner as any other load. The weight actually lifted at the Britannia Bridge, with only three presses, was equal to that of a vessel of 1,800 tons.

The steady action of the hydraulic press, its extreme simplicity, its small amount of friction, as well as its great durability and economy, render it pre-eminently the best available power for raising heavy weights with low velocity. It is, indeed, more than probable, that had the problem of raising a vessel presented itself originally in all its present magnitude, no other power would have suggested itself; but the progress of dock improvement, like all mechanical progress, naturally kept pace with the requirements of the day, and as ships became larger, a simple enlargement of the original rude method was the natural result.

The earliest kind of graving docks is illustrated by the practice of the Greeks, who ran their triremes aground on the sandy beach of their tideless sea, and then, dragging them bodily out of reach of the water, surrounded them with earthworks for their protection; an 'arsenal' was thus improvised wherever required. A natural improvement, where the ground was suitable, was to prepare an inclined plane of timber to facilitate the operation. Where the tides were available, the vessels were simply beached at high water during spring tides, and there left high and dry till the following springs. The 'Great Eastern' was docked in this manner in Milford Haven. In situations, however, where the formation of the beach allowed of it, a convenient bed or 'grave' was dug for receiving the vessel during high water at springs, such excavation being protected from the ingress of the water at the following springs, by an artificial bank thrown up in the interval. This was the first Graving Dock. A similar dock is at the present day in use at Hong Kong, the mud bank being protected by basket fascine work. It is remarkable, that not only do all these expedients continue in their original form, but the principles involved have in no way been departed from; and a modern first-class graving dock, even now, differs in nothing, but its dimensions and details of construction from these first models.

The ordinary Dry Dock, at present in use, in tidal rivers, is generally a simple excavation, lined with timber, usually with a brick, or concrete floor, and, to exclude the tide is furnished with a gate, or floating pontoon—first introduced by General Bentham at Portsmouth dockyard. The vessel enters at high water; the entrance is then closed, and as the tide goes down, the dock empties itself through a tidal sluice, and the vessel settles down on the blocks prepared for it, being at the same time shored horizontally, to prevent its heeling over. The sluice being closed, the returning tide is excluded by the gate, and with a little pumping to keep down the leakage, the vessel is kept dry enough for access. In a tideless sea, a graving dock is precisely similar, except that the whole of the water has necessarily to be pumped out. As vessels increased in dimensions, these docks became important works. They were lined with solid masonry, the sides being constructed with steps, technically called altars, for the double purpose of affording convenient access, and also for the support of the necessary struts for shoring. Pumping machinery on a large scale was added for rapidly exhausting the water, or for rendering the operation independent of tides, and a large amount of engineering skill of the highest order was displayed in improving all the details.

The following are the dimensions of one of these works, just completed at Portsmouth, sufficiently large for docking the 'Minotaur,' a vessel of 6,621 tons.

	Feet.	In.
Length of floor	400	0
Ditto at coping	426	0
Width at floor	35	0
Ditto at broad altar	75	9
Ditto at coping	99	0
Depth from coping to floor	33	10
Depth at H.W. springs at midships . .	28	4

The materials used were—

Granite to the level of the broad altar, 18 feet above the floor	135,000	cubic feet
Portland stone	26,750	„
Bricks	3,750,000	„
Concrete	135,000	„
Timber	81,000	„
Excavation	57,000	cubic yards

The inclined plane, or slip has also received its share of improvement. In situations where the foreshore is favourable, it is peculiarly applicable for small vessels, on account of its economy. The hydraulic press has been used advantageously as a hauling power, and great improvements have been introduced in constructing the cradles and other accessories. The difficulty, however, of berthing large vessels, and the strains to which they must be liable in being dragged up an inclined rigid plane, on separate and independent frames, supported on wheels, would be a bar to its use for large vessels, if other mechanical difficulties could be overcome. No slip has hitherto been constructed for large ships, and the difficulty experienced in moving the 'Great Eastern' down an inclined plane, is a fair illustration of that which would have to be encountered in dragging it up.

It will be seen from what has been stated, that a graving dock of large dimensions is, necessarily, a costly work. It must be accessible by a deep channel, and must therefore be adjacent to deep water. In a gravelly soil, or in rock penetrated by fissures, the difficulties sometimes are nearly insurmountable. A stone dock in such situations not only requires to be as water-tight as a floating dock drawing the same depth, but must be of sufficient weight to remain sunk. This involves in its construction a large amount of material, and the greatest nicety of workmanship; while, even in favourable circumstances, the entrance, with its deep cill and masonry walls, is always a costly work. It was, doubtless, the great cost of such docks, as well as the impracticability of making them at all, in some situations, which led to the use of floating docks.

Floating docks were originally built of timber and of moderate size; but the introduction of iron for shipbuilding added not only to the increased want of dock accommodation, from the frequency with which iron vessels require painting, but it also rendered more practicable the construction of floating docks of large dimensions. A dock of the earlier description was in use in the harbour of Marseilles, and was visited by the Author. It consisted of a timber pontoon with one end moveable; the sides being high enough to remain above water when the floor was sunk sufficiently deep to allow a vessel to float bodily into the interior of the pontoon. In this position, the pontoon was kept afloat by the buoyancy of the sides, which consisted of hollow boxes caulked water-tight, the vessel being properly secured immediately over the blocks prepared for it. The open end was closed by a moveable gate, and on pumping out the water, the pontoon rose with the vessel within it, which thus became accessible for repair.

An arrangement was also in use in which the boxed sides were dispensed with, by sinking the pontoon on to a prepared platform, the sides being still high enough to reach above the water level.

The same principles were applied to docks of large dimensions, constructed of wrought iron, and furnished with pumping machinery of the most elaborate character.

In America the system attained further development, there being timber docks on this principle at New York, Charleston, Savannah, Mobile, New Orleans, Portsmouth, and Pensacola. Mr. Stuart, who gives a full description of these works,[1] states, that the American Government attributed great importance to possessing the means of laying up their vessels of war out of the water, and under cover, on account of the rapid decay to which the ships were subject when afloat. They were also anxious to obviate the danger to which large vessels were exposed of being strained in the operation of launching.

To meet these views the docks at Portsmouth and Pensacola are so arranged that, after a vessel is placed on the pontoon, it may be hauled ashore on its cradle, on bedways prepared for the purpose. To effect this, the pontoon is grounded in a shallow basin on a platform constructed for it; the ways on the pontoon are thus brought on a level with the ways on shore, and the vessel is drawn ashore by a hydraulic press. Several vessels may thus be placed on the ways, or be launched with a single pontoon. The dimensions of the dock at Pensacola are:—

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[1] *Vide* "The Naval Dry Docks of the United States."

	Feet.	In.
Length	350	0
Breadth	105	4
Depth	38	3

The total cost was—

Floating dock	£111,140
Basin and subways . . .	70,645
Floating gate	2,600
	£184,385

The transverse floor girders are effectively trussed. Water-tight bulkheads are introduced, both in the floor and side chambers, and the water is pumped out by two 20 H.P. engines and eighty wooden pumps, placed on the sides of the dock. It was completed in 1851.

There is yet another form in use at San Francisco and Philadelphia, known as the floating sectional dock. The pontoon, instead of being entire, is constructed in separate and independent transverse sections, called 'camels,' any number of which may be used according to the size of the vessel to be docked. The camels are rectangular in form, and are completely submerged, to allow the vessel to float over the keel-blocks placed upon their decks. In order to secure stability in their submerged state, they carry at each end a detached floating chamber, capable of being raised or depressed, by appropriate gearing placed in framed timber towers attached to the ends of the pontoons. As the whole is timber, the camels remain afloat even when filled, and are sunk to the required depth by raising the floating chambers, their additional weight being sufficient to sink the sections, and to maintain their stability at the same time. The water is pumped out of the camels till the vessel rests on them. They are then grounded in a basin prepared for the purpose, and the vessel hauled ashore as before.

The Philadelphia Dock has nine sections, each 32 feet wide, 105 feet long, and drawing 10 feet of water with a large vessel upon them. When used together, they form a dock 300 feet long, and 105 feet wide. Their total displacement is 5,800 tons, and the cost was £170,000. They are emptied by two 20 H.P., and two 12 H.P. engines, working three pumps at each end of each section, with moveable shafting.

Floating docks are necessarily limited in their use, not only by their enormous cost in construction and manipulation, but also by their great liability to accident from the slightest mismanagement. The raising of a vessel on such a machine as that just described is really a difficult engineering operation in itself. The dock at San Francisco was seriously damaged, and Her Majesty's ship 'Termagant' nearly capsized, in a recent attempt to place it on the camels.

The loss of the floating dock in the London Docks has been described, and a similar accident happened to that made for Sourabaya, Java. A large dock, erected at Rio Janeiro, was found utterly unmanageable, and was never used at all. The fatal disaster which occurred with the dock at Callao will be fresh in the minds of members, and indeed the history of a large number of these docks is notoriously a history of failures or disasters.

THE THAMES GRAVING DOCKS.

It was with a view of meeting, as far as possible, the objections to existing systems, that the Author proposed the Hydraulic Lift Graving Dock, as the most efficient and economical substitute for the requirements of the Victoria Docks.

It was ultimately constructed by a totally independent company under the title of 'The Thames Graving Dock Company.' The necessary capital, originally £105,000, was raised in shares of £1,000 each, and was privately subscribed.

The site selected was a plot of 26 acres of level land, lying between the Victoria Docks and the Thames, and below the level of high water. This site admitted of a direct entrance from the Docks, with a permanent water level, without the cost and delay of a special entrance from the river. The soil is a deep bed of bog and alluvial mud, on a substratum of gravel. The only excavation necessary was the lift pit, and its deep entrance to the dock, where a cofferdam was employed.

The depth of water in the lift is 27 feet; over the remaining water space it is only 6 feet, which is the maximum draught of the pontoons. In this shallow-water space there are eight pontoon berths, separated by jetties for workshops and access; each berth being 60 feet wide, and from 300 feet to 400 feet long, and surrounded by brick-retaining walls. The bottom was covered with a level layer of peat clay, to prevent leakage to the gravel beneath. A sluice through the surrounding bank renders it easy, at low water, to empty the whole of the space; but when this is done, a dam must necessarily be thrown across the upper end of the Dock, to cut off the access to the Victoria Docks. The area of shallow water is 16 acres, affording sufficient space for floating fifteen or twenty pontoons, which, it was estimated, was about the number that might be kept employed by a single lift.

The docking of a vessel consists of two distinct operations. First, the direct raising of the weight on the lift; second, the transportation of the vessel to any convenient position for its repair on the pontoon.

The lift is a direct mechanical appliance for raising the vessel by means of hydraulic presses. It consists of two rows of cast-iron columns, each 5 feet in diameter at the base, and 4 feet in diameter above the ground-level, and sunk about 12 feet in the ground. The clear space between the two rows is 60 feet, and the columns are 20 feet apart from centre to centre, and are placed on each side of the excavated lift pit, in about 27 feet of water. There are sixteen columns in each row, giving a length of 310 feet to the Dock; but, as vessels may overhang at each end, there is a practical working length of 350 feet. The columns were sunk in the usual manner, three or four being thus fixed per week. When the requisite depth was attained, the base was filled with concrete, and covered with a layer of 2-inch planks, to act as a cushion for the cast-iron seat on which the press rests. No great accuracy of position is required, as the suspended load tends to bring all the columns vertical, and if any column should, during use, be even sensibly thrust deeper into the soil, the ram follows its work, independent of the level of the press. The columns support no weight; but act solely as guides for the cross heads of the presses, which move in slots reaching from the top of the presses (just clear of high water) to the top of the columns. The column is covered by a cap, and each row is firmly connected together at the top by a wrought-iron framed platform, running from end to end of the Dock on each side. This platform forms a convenient permanent scaffold for raising the rams. The whole length of a column is 68 feet 6 inches. A scale is printed on each column to register the motion of the cross heads while rising or falling.

The presses and girders are managed as follows:—Each column encloses a hydraulic press of 10 inches diameter, with a length of stroke of 25 feet; the top of the press is just clear of the highest water, and it is kept in place by a collar or diaphragm in the column. The rams are solid, and each carries a boiler plate cross head 7 feet 6 inches long, thus extending 1 foot 9 inches beyond the column on each side. From the ends of the cross head are suspended, by wrought-iron bars, two iron girders each 65 feet long, which extend entirely across the Dock to the corresponding column and press on the opposite side. There are thus sixteen pairs of suspended girders, lying at the bottom in 27 feet of water, when the presses are lowered, but rising above the surface, when the presses are raised. They form a large wrought-iron platform, or gridiron, which can be raised or lowered at pleasure, with a vessel upon it. The detail of the machinery is identical with that employed at the Conway Tubular Bridge; and those who saw that bridge raised have only to imagine thirty-two tubes side by side instead of two, and they will have a perfect representation of the lift. The main girders are 5 feet 9 inches deep, of wrought iron trussed with a cast-iron top flange. The sectional area of each ram being 100 circular inches, a pressure of 2 tons per circular inch gives 200 tons as the lifting power of each press, or 6,400 tons for the whole lift; but to find the available lifting power, there must be deducted 620 tons, which is the weight of the rams, cross head, chains, and girders, leaving 5,780 tons for the pontoon and vessel. The presses were tested at 2½ tons per circular inch. The girders are designed for carrying the vessel as a load at the centre, although the load is distributed by the pontoon, and the wide base used for the blocks. The water is forced into the presses immediately beneath the collars at the top, this being an accessible position.

The grouping of the presses was an important consideration. If each press were worked entirely independent of its neighbours, it is evident that precisely the same quantity of water must be thrown into each press to avoid unequal strain. Again, if the whole number were supplied from a common head, the slightest excess of weight at any part of the platform or gridiron would lower that part, the water passing back through the pipes to the presses where less pressure existed; the same difficulty would be experienced with two groups, however arranged. Stability is, however, secured by arranging the presses in three groups. One half of the whole number, occupying the upper half of the lift, form one group, consisting of sixteen presses. The remaining eight presses on one side form a second group, and the opposite eight form the third group.

The presses in each group are all connected, so that perfect uniformity of pressure is secured in each as regards the individual presses; while the three groups are so arranged that their centres of action form a tripod support, upon which the pontoon is seated. As any one point of the tripod may be raised or lowered without regard to the other two, by the most simple manipulation, the pontoon can be either maintained perfectly level, or any inclination can be given to it that may be desired.

Any pair of presses may be instantly cut off in the valve room by means of a plug, during the operation of lifting, without interrupting the process. One or more of the end pairs is almost invariably out of use, except with vessels of the largest class. No delay, therefore, arises from the failure of a collar or pipe, and even should a press burst—which appears an impossible contingency—the water can only escape slowly through the half-inch pipe which feeds it; and by opening the escape valves in the other groups, vessels, partially raised, descend slowly and steadily into the water.

Additional provision against such a contingency has been provided, by an arrangement which gives instantaneous means, in the valve-house, of isolating every press from the rest. For this purpose, a special series of valves is provided for each group, which can be closed simultaneously, by means of an eccentric shaft. This arrangement, which forms so prominent an object in the valve-house, has been found unnecessary, and will not be again employed. The force-pumps are 1⅞ inch in diameter. There are twelve pumps, worked by direct action by a 50 H.P. engine; six of these pumps are used for the large group, and three pumps for each of the smaller groups. The power when required is increased by cutting off one or more of the pumps. The engine-house is, unfortunately, 112 yards from the lift, the water having to be driven all this distance through pipes only ½ inch in diameter. On account of the distance of the engine, a valve-house, for the manipulation of the presses, is erected on the platform alongside the Dock. During an operation the engine continues to pump, and the valveman throws the water into either group, or to waste, at pleasure. The raising of a vessel occupies about twenty-five minutes. The pipes and presses are, to a considerable extent, sheltered from frost by their position; and during the severest cold, a few occasional strokes of the engine are found sufficient to keep all in motion, and prevent congelation.

The pontoons are not essential for raising, or docking a single vessel, for it is evident that the lift, as described, is all that is required for that purpose. The girders might be connected together by other longitudinal girders, so as to form a sufficiently rigid platform, or the whole might be formed into a pontoon, which would support a vessel after it was raised. Such an arrangement would be more economical and convenient than any ordinary dock, but it would accommodate only a single vessel; whereas, by the use of separate pontoons, an indefinite number of vessels may be placed afloat, whilst the most costly part of the system remains constantly available.

The following is the arrangement adopted:—An open pontoon, proportioned to the size of the vessel to be docked, is selected. Keel-blocks and sliding bilge-blocks, adapted to her shape, form part of the pontoon, which is placed on the girders, and sunk with them to the bottom of the dock. The vessel is brought between the columns, and moored securely over the centre of the pontoon. By lifting the girders, the keel-blocks are first brought to bear under the keel of the vessel; the side-blocks are then hauled in, by chains laid for the purpose on each side the dock, and the grid-iron and the pontoon, with the vessel upon it, are then all raised by the presses clear of the water. The pontoon is provided with valves in the bottom, and thus empties itself of water. The valves are closed, and the girders again lowered to the bottom, but the pontoon, with the vessel upon it, remains afloat. Thus, in about thirty minutes, a vessel, drawing 18 feet of water, is left afloat on a shallow pontoon drawing only 4 feet or 6 feet, and may be taken into the shallow dock prepared for its reception. These docks are surrounded by workshops and tools, with shelter for the men close up to the bulwarks of the ship. The vessel is, in fact, brought bodily into the centre of a convenient workshop. It is taken to the smiths', or the carpenters', or the machine shops, according to the nature of the repairs required, and is moved easily from one to the other.

The number of vessels that can be thus docked is limited only by the number of pontoons, each pontoon constituting a separate and independent dock. The pontoons, which are all about 58 feet wide, vary in length and depth according to the class of vessel intended to be docked, and are rectangular in form, and open decked. The sides are vertical, and are strengthened longitudinally and transversely by wrought-iron girders, running from side to side, and from end to end, and thus forming a series of rectangular divisions. The pontoons are divided into water-tight compartments, by means of bulkheads formed of the girders, each compartment being provided with a circular valve in the bottom, closed by a screw-shaft. The transverse girders are 8 feet apart, and support the bilge-blocks on their upper flanges. In the largest pontoons these girders form inclined planes, declining in height towards the centre, to facilitate the running-in of the block frames. There is a strong longitudinal centre girder, with a broad top flange, for supporting the keel-blocks; on each side, the two other longitudinal girders are placed equally distant, and in the line of the side-blocks. There are seven pontoons at present in use, their dimensions being given in the following Table :—

No.	Length.	Depth.		Net Tonnage.	Cost.
	Feet.	Feet.	In.	Tons.	£.
1*	241	6	2	1,750	5,130
2	241	5	6	1,650	6,086
3	201	5	6	1,450	5,725
4	201	5	6	1,450	5,683
5	157	5	0	1,100	4,100
6	134	5	0	930	3,600
7	321	7	0	3,000	10,853
		Partly constructed.			
8	281	7	0	2,450	..

* No. 1 pontoon was framed with wood in its outer compartments, and only built 5 feet high, the waling being afterwards added.

The cost of the lift and other machinery was:—

	£.
The lift complete and fixed, including columns, presses, girders, and pipes	20,300
The 50 H.P. condensing engine and pumps, boilers, and connections, including the valve arrangement (not a necessary part of the apparatus)	3,600
The connecting pipes, including all testing, fitting, and fixing, supply of workshop tools, experiments, &c.	1,628

It may be remarked, that a high-pressure engine would be more convenient, and far more economical.

There are, doubtless, many details which may be materially improved after seven years' experience; but it is a proof of the simple character of the machinery, that no modification, or renewal, or repair of any kind has been necessary, although, at the end of last year, 1,055 vessels had been lifted, of an aggregate tonnage of 712,380 tons, without a single casualty.

No remark is necessary on the calculations employed in so simple a machine. The area of each pump being $3\frac{1}{2}$ circular inches, their aggregate area is 42 circular inches. Similarly, the aggregate area of the thirty-two presses is 3,200 circular inches. The action, disregarding friction, is therefore identical with that of a lever, whose arms are respectively 42 and 3,200. The respective velocities and pressures are thus obtained by direct proportion, the power being a 50 H.P. engine on the long end of the lever, and the weight lifted being the vessel on the short end; while it may be remarked that, in a stone dock, the power employed bears no proportion to the work done, and is always immensely greater.

As regards the advantages of this pontoon, it will be seen that it differs, in many respects, from an ordinary pontoon. In the first place, it is open without a deck; the sides are no higher than is required for the load; it is not encumbered with any pumps, or machinery, or inaccessible chambers; when submerged, its stability is insured by the presses, and, when afloat, its form gives it the greatest amount of stability possible; while the simplicity of its construction renders the cost extremely moderate. The durability may be estimated from the fact, that the effect of seven years' wear and tear is imperceptible, although, during all that period, the pontoons have never been repainted.

The pontoon affords special facilities for blocking vessels, and for access to them when blocked. This arises from the clear space which the open deck of the pontoon affords for blocks and scaffolding, and from the fact, that the keel of the vessel is everywhere accessible, on account of the deep space beneath it. This peculiarity has been found of great value, since the renewal of a keel, in an ordinary dock, is a work of great difficulty. There is, however, no feature of greater importance than the absolute freedom from strain afforded by the partial elasticity of the pontoon, and the means of balancing it by admitting water. To appreciate this, it must be borne in mind that the object in supporting a vessel out of water should evidently be to replace, as precisely as possible, the pressure which the water affords, when she is afloat. It is in this respect, that a stone dock is so deficient, and the effect on large vessels so notorious. An iron-clad vessel weighs about 20 tons per foot run; but, if divided into a series of transverse sections, the support at every section will be equivalent to the displacement of that section. At the centre of the vessel, where the bulk is large, it will be much greater than at the bow and stern; but when supported on the rigid floor of a stone dock, the stiffness distributes the weight nearly uniformly, over the whole length of the keel. Looking at the ship, then, as a girder, and the buoyancy, or the supports, as loads laid on, the girder is evidently, in the two cases, subjected to totally different strains. The superior buoyancy of the centre of a vessel frequently shows itself by the hog-back form it assumes, or by the wrinkling of the copper, and, in an ordinary dock, this last appearance, not unfrequently, indicates the strain to which vessels are subjected.

Again, the bottom of a stone dock is a narrow floor prepared for the keel-blocks, with no means of support under the sides of the vessel, where the whole weight is concentrated. As the water is lowered, the vessel rests, at first solely on the keel, and the enormous and injurious strains, thus thrown on the ribs of an iron-plated vessel, may be imagined. Indeed, no greater departure from the support previously afforded by the water can be conceived. It is true, that the forest of struts always placed between the vessel and the altars on each side, do, to a great extent, replace the horizontal pressure of the water, by tending to keep the sides together; and without such support no vessel could be so docked at all. But the Author need not point out to Engineers, that in dealing with a weight of 20 tons per foot run, no vertical support of any value can be obtained by struts, which must of necessity be nearly horizontal, and which, when slightly inclined, have been known to disturb the solid masonry steps of the dock itself. As soon as the water is pumped out of the dock, proper shores are added under the bilges, but the mischief is then done, and the quantity of timber consumed in these blocks and shores is, alone, an item of cost many times greater than the whole expense of docking such a vessel on the permanent blocks of a pontoon. The whole current cost of the latter operation, including preparation of blocks, coals, and staff, does not average £3 per vessel, in the Thames Graving Docks; and it is performed as follows:—

The permanent keel and bilge blocks are first packed up with reference to the form of the vessel, and secured together with 'dogs.' The bilge blocks move on sliding frames, and as soon as the keel touches the pontoon, the frames are drawn by chains down the channels prepared for them, and are thus made to abut solidly against the ship in a position nearly vertically beneath the sides: a ratchet prevents their return. The vessel is thus fully blocked before being lifted, and, when lowered again and left afloat, the elasticity of the pontoon secures an equable bearing on each block, and prevents any block doing more work than its neighbours. The vessel is supported at numerous points, by pressures analogous to the pressure from the water itself: it is also resting on a base 30 feet, or 40 feet wide, so that without shores, its stability is beyond all question.

Again, the support is rendered proportionate to the displacement, by admitting water into the compartments, as in the American Floating Dock; thus any excess of pressure shown by the blocks is immediately remedied. When the pontoon is longer than the vessel, the end compartments are invariably left open, and only that portion of the buoyancy of the pontoon is retained which the circumstances require.

The stiffness of a pontoon depends on its depth. The amount of longitudinal stiffness necessary for a pontoon when afloat is very small; for, if the balancing by means of the water is properly regulated, no strain is thrown on the vessel from deficient rigidity. It is indeed evident, that if a pontoon were perfectly elastic, and became a mere sheet of india-rubber, that the strain would be absolutely identical with the strain in the water. It is however advisable that the strength of the pontoon, laterally, should be nearly sufficient for supporting a vessel resting entirely on the keel-blocks, as the bilge-blocks are necessarily removeable. It is also necessary to retain a considerable amount of longitudinal strength, on account of the uniform character of the lifting force; this is, however, modified by cutting off one or more pair of intermediate presses; and in docks which are now in preparation, the presses are not placed at equal distances, but nearer together at the centre of the lift than at the ends. The same result may be obtained by slightly increasing the area of the centre presses. The whole subject of blocking is full of practical interest, and nothing will excite more attention, in a visit to the Docks, than the extreme facility with which the operation is performed, and the ease with which a single operator appears to handle these, apparently, unwieldy structures.

It is unnecessary to dwell on the subject of the stability of the pontoon itself when afloat: the Author would only observe, as the result of calculation, that the effect of a gale of 20 lbs. pressure per square foot on the broadside of a frigate, with every sail set perpendicular to the pressure, would be an extra immersion of only 5 inches on the lee side of a pontoon. In practice, no gale ever produces any appreciable motion whatever.

Although, however, the tilting effect is inappreciable, yet during a gale of wind the navigation of a vessel, on the deck of a pontoon, requires proper caution. This was illustrated by a singular accident, which occurred during the great gales of 1860. A vessel, which had been repaired, was being towed by an 8-inch hawser across the open dock during the height of the storm; the rope gave way, and the pontoon, with the vessel upon it, drifted, with rapidly increasing velocity, entirely across the dock, when it came in contact with two empty pontoons, lying alongside the jetty. The immediate effect was to stave in one of the compartments, which filled, and the pontoon rebounded back some distance into the dock; the wind, however, catching it a second time, it again struck the pontoons and unfortunately staved in a second compartment, and sank. The vessel, however, remained upright and uninjured on the blocks. The operation of floating it again was characteristic of some of the advantages of the system. A low dam was placed across the upper end of the dock, in the shallow water, and a few feet of water were run out of the dock, by means of the sluice. This was sufficient to expose the side of the pontoon above the water, the damaged plates were then made tight with clay, and on pumping out the remaining water in the pontoon, it was left afloat again, and placed on the lift till it was repaired.

As to the practicability of enlarging the system to meet the requirements of vessels of any size, it is evident that by simply placing an additional column between every existing column in the present lift, the lifting power would be doubled, or made 6,400 tons, without altering the strain of a single bolt. The same result might be obtained by placing two presses in each column, and this was the form adopted in the designs prepared, by order of the Lords of the Admiralty, for vessels like the 'Minotaur.' The lifting power may further be indefinitely increased by enlarging the area of the presses, and no mechanical difficulty would be experienced, with even ten times the weight alluded to.

Again, the weight that could be lifted may be doubled, without any alteration of the presses, by using a close-decked pontoon instead of an open one. An additional lifting power equal to the displacement of the pontoon would be thus obtained by pumping out the water: the presses would insure the necessary stability and complete the operation. A dock in this form was also designed for the Admiralty on their official request; but it is evident, no advantage could result from the substitution of the pontoon as a partial lifting power: it is, in any form, a far more costly arrangement, and its combination with the presses removes none of its disadvantages.

Although no doubt can exist as to the capability of the lift to deal with any required weight, the Author feels bound to state that some doubts have been expressed as to the expediency of docking vessels of the largest class on a pontoon without the ordinary horizontal shoring, which forms so prominent a feature in an ordinary dock, and which would be naturally abandoned with reluctance by an old shipwright. There are, moreover, some localities where the docking of the largest class of vessels is so rarely required, that the cost of a special pontoon is scarcely warranted: an arrangement has accordingly been perfected which will fully meet these requirements. Altars or steps might undoubtedly be placed on a pontoon; but to secure an efficient base, a considerable increase of width would be necessary, as well on the pontoon as in the main girders of the dock. The requisite base may, however, be obtained by projecting the lifting girders beyond the columns, on each side of the dock. It is further proposed to combine them by longitudinal girders, and then, by close plating the whole externally, to convert the platform or gridiron into a water-tight pontoon, with framed altars on each side, of sufficient height to remain above water when the pontoon is sunk. The presses would then lift an entire floating dock, of the ordinary form, which when raised, would remain afloat, independent of the presses, but be capable of being moved from its fixed position.

Smaller pontoons might be used in the ordinary manner, by lifting them on the top of this fixed pontoon. This would afford efficient means of shoring in the ordinary way, and effect some economy as regards the construction of an independent large pontoon; inasmuch as the main girders of the dock would take the place of the transverse girders that would be required for the pontoon. This arrangement is specially applicable to places where only a single dock is required.

Numberless other modifications suggest themselves. The pontoon may be used in any ordinary dock, or in a tide-way where the rise and fall is sufficient, without a lift at all. The tide may also be made available in diminishing the stroke of the presses to the extent of its rise. The lift may be erected in any open channel where there is sufficient shelter, and whatever be the character of the soil—the only limit to its application is in places where the depth is too great for fixed columns; but even for these situations a modification has been devised by Mr. W. H. Walker, which possesses great merit. This gentleman proposes to float the presses themselves, on a series of pontoons, employing machinery very similar, in many respects, to that described. The dock thus becomes a moveable floating dock, capable of being moored anywhere, and of its position being changed when desirable. It is also very portable in its parts.

In conclusion, it must be admitted that however successful this system may have proved in a mechanical point of view, its early history was characterized by complete want of commercial success. The first misfortune, which befel the Company at starting, was the irreparable loss of its Chairman, the late Mr. R. Stephenson. The Company had commenced with insufficient capital, and before completing their works, they found themselves deprived of the master mind, on which they were so much accustomed to rely. They possessed no large pontoons; and it was originally intended to rely solely on the dues from docking as a means of revenue; they were surrounded by numerous competitors, on each side the Thames; and to such an extent was competition carried, that the docking of vessels was, for a long time, performed in the Port of London without any charge whatever being made for dues. As the officers of the Company were restrained, by strict instructions—issued by the direction of the leading proprietors—from undertaking repairs, or entering into any mercantile arrangement, they were helpless. And it was seldom that even half the amount of the intended charge for docking a vessel could be obtained though that charge was only 6*d.* a ton for the lifting, and 2*d.* per ton per day for the use of the pontoon. It then became evident, that the only alternative was for the Company to entirely change their system of business; to become themselves manufacturers, and to do all repairs, &c. The immediate result has been successful beyond expectation. The Company now possess one of the most perfect and extensive ship-repairing yards in the kingdom, with spacious workshops, and abundant machinery for every class of work. The weekly payments, for labour only, reach £1,000, and although they now possess seven pontoons, equivalent to seven distinct graving docks, yet, to meet the increasing requirements of their trade, others are being constructed. The number of vessels that resort to the establishment is increasing, and among them are included some of the largest vessels that frequent the Port of London.

The principal features of the system may be conveniently summed up, as follows:—

1st. Its economy, as well in its first construction, as in its subsequent maintenance.
2nd. Its adaptability to almost any situation, especially in harbours or tideless seas.
3rd. The capability of almost indefinite extension, by the construction of additional pontoons, or as regards the lift, by the addition of extra columns.
4th. The simple and durable character of all its parts, and their perfect accessibility.
5th. The short time required for its construction and erection.
6th. The rapidity of its manipulation, and the small staff required.

7th. The convenient access afforded to all parts of the ship, and, especially in painting iron ships, their free exposure to light and air.

8th. The freedom from strain with which vessels, even in cargo, may be docked.

9th. The means afforded of rendering any area of shallow water available as a dock for the largest vessels.

The above characteristics are the result of direct experience; but it may be useful to indicate others that may be anticipated.

In the first place, it is evident that this system affords ready means, by the construction of a shallow canal, of transporting the largest vessels in cargo, either across an isthmus, or over river shallows; and of removing vessels of war inland, either for their protection, or for their employment as a means of internal defence.

The pontoon affords a convenient and economical method of avoiding the risk and cost that attend the launching of new vessels. It is intended by the Company to build vessels on their pontoons, which may be grounded for this purpose on a level bottom, and an immoveable platform will be thus at once secured. The launching will, then, be reduced to simply lowering on the lift. In this manner vessels of any dimensions may be constructed in a shallow estuary.

Vessels may, when unemployed, be laid up and kept dry under shelter, and thus preserved from decay, while the launching of a whole fleet would only be the work of a few hours.

No naval establishment possesses sufficient dock accommodation to provide for the numerous casualties that occur during war. It will not be doubted, that a lift, with sufficient pontoons, would prove of the utmost value, in affording immediate means, after an action, of docking a whole fleet of gun-boats and other craft, thus leaving the existing stone docks for routine use.

Lastly, it is evident, that should this system become as universal in its application as the Author confidently believes it must eventually do, such a result would inevitably lead to important modifications in the general arrangements of all large naval establishments. If fleets can be thus laid up, and vessels be built and navigated in any shallow-water space, no necessity can exist for that large area of floating dock accommodation which is now required; and a considerable portion of the enormous expenditure which characterizes such works may be economised.

The Paper is illustrated by a series of diagrams, from which Plate 13 has been compiled.

[Mr. Edwin Clark

Mr. **Edwin Clark** remarked, that his object was to court the fullest discussion on the subject of these docks, and with that view, he had endeavoured to make the Paper as comprehensive in its details as he could. He took this opportunity of expressing his obligations to those gentlemen who had assisted him in bringing these docks to their present state, (more especially Mr. Bidder and the late Mr. Robert Stephenson,) not only in the designs, but also in the financial part of the undertaking, by taking upon themselves personally a large share of the first outlay. He had also to thank Mr. John Heppel for the very ingenious suggestion, which had been described, of arranging the presses in three groups, instead of in the mode originally intended. Mr. Clark expressed his readiness to elucidate any point upon which further information was desired.

Mr. **Abernethy** inquired whether the statement of cost included all the necessary excavation in connection with the lift, in fact all the preparations for receiving the machinery. Some information on that point was necessary, to enable a comparison to be made of the cost of this dock, with that of graving docks of the ordinary description. It was stated, that the cost of the operation of lifting was about £3 per vessel. He presumed that was the average price.

Mr. **Clark** replied, that the cost of the excavations had not been given. Obviously the excavations for receiving the pontoons, if any were required, would form a considerable item in the cost of the work. In some places, however, the whole work consisted simply of sinking columns. But he would before the close of the discussion, give this information in detail. The cost of lifting named was an average for all the vessels lifted.

Mr. **Charles Capper**, having had opportunities of seeing a great deal of the operations of this dock, was satisfied that, as a mechanical contrivance, it was perfect. The commercial success of the undertaking was, however, the question which came more within his own province; for however successful it might be as a mechanical contrivance, if it were not commercially successful it would be of no use. The Author had described the circumstances under which this dock was a commercial failure, in the first instance. It was assumed, incorrectly, that the mere charge for lifting the ships, and the rental for the use of the pontoons would be sufficient to pay a remunerative return upon the outlay. There were about twenty-seven docks on both sides of the river, the proprietors of which docks were repairers of ships, as well as dock owners, and it was to their interest to sink the charge for the use of the docks in order to get the repairs of the vessels. This Company having at first no mechanical appliances for repairs, and being subject to the competition referred to, the commercial failure of the

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project would be readily conceived. It did not matter where dry docks were situated in this country, whether on the Tyne, or at Southampton; the system of charges for merely docking and undocking, and for the use of the dock, would not pay. The Tyne dry docks did not pay more than 2¾ per cent. if the profits were reckoned by these charges only; and the docks at Southampton only yielded a similar return, viz., 2¾ per cent. upon the £166,000 of outlay. It was obvious that, to make these docks, or any ordinary graving docks, successful speculations, the proprietors must, to a certain extent, go into the business of repairing the ships. If they did that, as was the case in this instance, they would turn a loss into a respectable profit. The last year before the Thames Graving Dock Company undertook repairs, the loss upon this dock was about £4,000, but since the repairing had been superadded, although it had only been as yet perfectly carried on for nine months, a profit had been realized of between £11,000 and £12,000 per annum, which of course made a very material difference in its commercial character. This dock experienced another drawback. Being the first of the kind on the Thames, many modifications were required to adapt it to the peculiar requirements of the port. These were all additional expenses, of course, as usual, charged to capital; and when revenue had to pay upon capital employed in making experiments, it affected the result. He was bound to say, that the undertaking was now approaching that state in which he wished to see it; and he believed before long it would be one of a highly remunerative character.

Mr. P. Hedger endorsed all that had been said as to the unremunerative character of the docks at Southampton, the return being not more than 2¾ per cent., or 3 per cent. upon the outlay. The repairing of ships formed no part of the business there. At Southampton there were three dry docks, one of which could accommodate any ship yet built, except the 'Great Eastern.'

Mr. A. Giles said, the Paper contained much that was interesting, and the mechanical arrangements of this dock were no doubt of the most admirable and perfect character; but he thought the ordinary graving docks had been undeservedly condemned. Before the advantages of this dock could be compared with those of ordinary graving docks, it was necessary to be informed what had been the total cost of the existing works.

Mr. J. Scott Russell, V.P., thought additional information was required to enable a comparison to be made between this system and that of a floating dock to be filled with water by a steam engine, and emptied of water by the same means; and especially was information required in order to form an approximate estimate of the comparative cost of the system under discussion, and that of simply filling and emptying the tanks in the floating dock, which accomplished all that was done by the hydraulic apparatus. He yielded to no one in admiration of the ingenuity and ability displayed in the whole of this apparatus, but he thought there was a difficulty in comparing it fairly with stone docks. Information was also needed as to the advantages and disadvantages of having a vessel which was ‘hogged,’ or out of shape, placed upon an elastic pontoon which would yield to its distortion, or of placing it on a rigid pontoon which would not yield to its distortion, but which would compel it to come back to the straight line on which it was originally built, and which it was very desirable it should come back to, before it was repaired.

Mr. Edwin Clark stated, that the cost of the excavations for the lift pit proper was £2,000, the contract being let at 1*s.* per cubic yard. The cost of the whole of the excavation, including the lift pit and the deep channel leading from the lift pit to the Victoria Dock basin on the one hand, and to the shallow water used for the pontoons on the other hand, amounted to £3,593. The lining of the dock with concrete and masonry was executed at a cost of £4,473; and the timber platform all round the dock was provided at a cost of £4,618. The outlay upon the coffer-dam in the dock was £6,543. In addition to this the engine-house and valve-house were erected at a cost of £2,200, making the total cost in connection with the lifting apparatus, £21,427.

Sir Charles Fox thought the term "power," as applied in the paragraph of the Paper which stated "That power, when required, is increased by cutting off one or more of the pumps," was an erroneous use of that word. The word "force" would more correctly convey the notion of the Author, inasmuch as no reduction in the number of the pumps could affect the power of the prime mover, in this case, a steam-engine of 50 H.P. The only result of cutting off pumps would be, to let the whole of the above power be expended upon a smaller number of pumps, and consequently to increase the pressure in the cylinders in work, and so to spread the operation of lifting over a longer period of time, but in no way could the power be interfered with by that operation. It was stated in the Paper, that the rams were each 10 inches in diameter, having, of course, an area of 100 circular inches: that their lifting capacity being 2 tons per circular inch, was therefore (less the weight of the ram) 200 tons each. It was further stated that these rams had been proved, to the extent of 2½ tons only per circular inch. Now it seemed to him, that if some of these pumps were thrown out of work, and the pressure thereby increased in the cylinders still in operation, the limit of half a ton for proof was far too little. It was known, that the Board of Trade in dealing with a bar, which was considered to be capable of carrying, as a minimum, 20 tons, would not permit it to be loaded to more than 5 tons; but then that rule was applied to structures which were exposed to many trying circumstances and influences, such as corrosion, vibration, &c., and therefore, though he did not think the proof of hydraulic presses need be anything like that of double the actual pressure employed, still it should not be less than 50 per cent. more. He should not be satisfied with exerting a pressure of 2 tons per circular inch, unless he had proved the press to about 3 tons; and, if it were his intention to increase the pressure in any individual cylinder beyond the 2 tons, he would prove that cylinder to at least 3 tons and perhaps 4 tons. After a very long experience in the use of hydraulic presses, he had arrived at the conclusion, that a pressure of 2 tons per circular inch was the one practically the most desirable, and with that as a maximum, he would not feel comfortable with a press proved to less than 3 tons; and if any real advantage was to be obtained by cutting off any of the pumps, the presses ought to be proved to the extent of 4 tons; and, therefore, this operation of cutting off pumps could not be performed, with safety, with a proof of only half a ton beyond the ordinary working pressure of 2 tons in the cylinders. As to the commercial element of the Hydraulic Lift Graving Dock, compared with the old form of dry or graving docks, he thought the statements contained in the Paper failed to carry conviction in its favour to the minds of those who would take the trouble of making a careful comparison between the two. It was admitted, that in consequence of the competition of dry docks in the Thames, it was not till about nine months ago, when the Company took upon themselves the additional business of repairing vessels, one open to but little competition, that the plan ceased to be attended with considerable loss. Up to that period the revenue account of the Company showed a debt of £4,000 against the working of the hydraulic lifting apparatus, and it was only by the Company having embarked in the new business of ship repairers that its pecuniary position was improved—not by the use of this lift, but by the profits of their new avocation; while the dry or graving docks at Southampton, where ships were not repaired, paid a return of 3 per cent. upon the capital embarked in them. The conclusion at which he had therefore arrived was, that this description of dock *per se* had hitherto failed to show satisfactory commercial results.

Mr. F. J. Bramwell would, in the first instance, add a few words on the history of floating-docks. This history had been touched on by the Author, but he had not carried it back to the earliest times. Mr. Bramwell found it recorded that, in 1785, one Watson, a shipwright on the Thames, constructed a wooden floating-dock in which a large vessel called the 'Mercury' was repaired. In this construction of floating-dock there was an end-gate, which was lowered to admit of the vessel entering, and the gate being afterwards raised, the water was pumped out of the dock. Mention was also made, in 1776, of one Aldersley having constructed "a large portable dock in which to float vessels."

As regarded the more modern history of floating-docks, the Author had alluded to the box-dock and the sectional dock, both of which had been used in America; but he had omitted to mention a dock that was used in that country prior to either of the other two docks; and Mr. Bramwell was somewhat surprised at this, as, in its modified construction, it appeared to him to be one that ought to have found favour with those who advocated the raising of vessels by hydraulic presses. He alluded to the dock which, from its original construction, was known in the United States as the Screw Dock, but which was afterwards worked by hydraulic power. He had placed on the wall a rough drawing, showing this dock as thus constructed with hydraulic power. It would be seen that it consisted of two parallel rows of piling placed at right angles to the shore; these rows of piling being wide enough apart, sufficiently roomy, and in a sufficient depth of water to take in between them the largest ships the dock was competent to lift. The piles in each row were connected at the tops by timbers, on which was a gangway. From one row of piles to the other there were, at frequent intervals, transverse timbers. These timbers were lowered into the water, and the ships to be docked brought over them. At each end of each timber there was a chain, by which it was suspended. These chains went upwards, and passed over pulleys placed on the frames connecting the heads of the piles, and then all the chains on each side were connected to a horizontal traction-bar, which was a very strong wooden bar extending the whole length of the dock, and supported on rollers. To each traction-bar, there was a powerful hydraulic cylinder, and on this being worked, the traction-bar was moved endways, and thereby the whole of the chains attached to it were uniformly drawn; and in this manner the presses on the two sides being worked at equal rates, the whole of the beams below the vessel were simultaneously and uniformly raised, lifting the vessel that was upon them out of the water. He had seen that dock when at New York in 1853, and he believed it had been in operation for many years previously, and with perfect success. It appeared to him to be interesting as regarded the present Paper, to the lifting of vessels by means of hydraulic presses.

Having made these few remarks upon some points omitted from the history of floating docks and of docks worked by hydraulic power, he would now remark on the subjects mentioned in the Paper. He understood the Author to lay considerable stress on an advantage possessed by the Hydraulic Lift Graving Dock, that the bilges of the vessels were supported almost immediately upon the keel taking the blocks, and a contrast was made between this mode and that practised in ordinary dry docks, where until the whole of the water was removed, so as to admit of the workmen fixing the shores, the bilges remained unsupported. He believed, with the Author, that this ability to give support to the bilge of the vessel at once was an important matter. He thought that in all cases after the natural support of the water was removed, it should be compensated as speedily as possible by some other support. But although he entirely agreed with the Author in this view, he thought it ought to be clearly understood, that that ability to support the bilge at once was not a property peculiar to the dock under consideration. It would be found that it existed in the New York Screw Dock, to which he had just referred, and it existed also in the Sectional Dock. The Author, therefore, in availing himself of the system of blocks to support the bilges, had done no more than had been done in previous docks, nor than might be done in any other dry dock; at the same time he was glad to find that the Author approved of that which he (Mr. Bramwell) believed to be a most useful precaution in the docking of ships.

He would now go to another point which was raised by the Author, which was this--that, in his judgment, not only was it unnecessary that the bed on which a vessel was received while being docked should be rigid, but that it was absolutely undesirable that it should be so. Now he must say he entirely dissented from this view. For although at the present day there were many iron ships which were so well built as to be efficient girders in themselves, and although even wooden ships were now much better trussed and braced than they used to be in days of yore, when they were little more than an assemblage of timbers side by side, without proper trussing and fastening, nevertheless he considered that a properly-constructed dock should be one in which any vessel might repose in the certainty of not being called on to rely upon its own strength as a girder to compensate for the want of strength in the dock, and where, therefore, a ship, however weak in its construction, or however old or damaged, might be taken with the assurance it would not get out of shape.

To explain himself still further, he might say that when he had been consulted on the subject of floating docks, he had laid it down as an axiom, that the dock, if properly made, ought to possess so much likeness to a stone dock in its rigidity, that if a ship placed in the dock were cut into slices, these various slices ought to retain their relative position to one another, although the weights of the various slices would, if of equal thickness, be very different. As bearing on this point of the difference of weight per foot run, he wished to call attention to the Author's mode of taking the weight of a ship, which he had done, as being, in extreme cases of armour-plated vessels, 20 tons per foot run, or 6,000 tons for a ship 300 feet in length. But Mr. Bramwell objected to the construction of a dock being based on the assumption, that a vessel had a uniform weight per foot run. Take the case of a ship 300 feet long, and weighing a not unusual weight for that length of 3,000 tons, it would be very wrong to assume that that ship weighed 10 tons per foot; the fact would probably be, that for each foot run amidships, she would weigh about 14 tons, and for each foot at the end only about 7 tons. The assumption, on the part of the Author, of uniformity of weight per foot run must, he thought, be admitted to be a mistake; and yet, upon this theory alone could the practice of a non-rigid bed be admitted, and certainly such an eminently non-rigid bed as the Author had put forward as his ideal of excellence, viz., a sheet of india rubber large enough to secure the vessel.

Having thus endeavoured to explain the reasons why non-rigid beds were bad, he thought he might be allowed to refer to the practice of ship-builders, to show that that practice coincided with the principles he had been advocating. It would be admitted that in building vessels, the greatest possible pains were taken to obtain a thoroughly solid bottom for the slip-way whereon they were built; and it was well known that considerable damage had arisen from the ground of a slip-way having occasionally yielded in parts. This showed the importance attached by ship-builders to having a rigid bed on which to build a ship. It seemed to him that that which required a rigid support while being built, required a rigid support while being repaired. He wished, on this point, to be allowed to refer to the very pertinent observation made by Mr. Scott Russell, that if a ship got out of shape while afloat, the thing wanted in repair was a dock that should bring her back into shape. Mr. Bramwell believed he was correct in saying, that about ten or twelve years ago, an impression existed in the mind of an inventor, that a rigid bottom to a dock was a bad thing; and he proposed to remedy this, by placing on the bottom of a stone dock a number of small hydraulic presses, on which the keel of the ship was to rest, in lieu of resting on the ordinary keel blocks. These presses were all to be connected by pipes, so that they might adjust themselves to the pressure of the keel. This arrangement was tried in one dock in London; but, as might, according to Mr. Bramwell's views, have been expected, was found to be injurious to the vessels, and had to be removed, and the rigid system of blocks restored.

It appeared to him that following upon this reference, to the effect of endeavouring to use for keel-block hydraulic presses, when coupled up into a system, came not improperly the consideration of the operations which took place in the Hydraulic Lift Dock, when raising vessels by the system of presses at each side of the dock. It was quite clear that so long as these were all united into one system, there was no remedy whatever against the vessel tilting either sideways or endways in the act of being lifted, and the Author had given well-merited praise to Mr. Heppel, for the suggestion of dividing the presses into three distinct groups. No doubt by this arrangement perfect command had been obtained over the raising, so far as related to keeping the lift horizontal; but this arrangement of grouping did not get over the fact, that the presses at the ends were exerting the same upward force as those in the middle; that was to say, a force representing the average load, and that, therefore, as a vessel was undoubtedly lighter at the ends than in the middle, it was lifted by an excess of force at the ends, and a deficiency of force in the middle; and the difference between the forces employed at the respective parts, and those forces actually required there to balance the weight of the ship at those parts, had either to be taken off by the ship itself acting as a girder, or by the strength of the pontoon or saucers so acting; and he feared, looking at the want of depth in the saucer, that it was upon the ship itself the strain must come; and this he looked upon as an undesirable point in the construction of the dock.

Upon this question of preventing an undue lifting of one press as compared with another, he would allude to a plan he had prepared for the use of hydraulic presses in certain operations in the manufacture of iron, where he had introduced a system of wedges, the withdrawal of which could be regulated at pleasure, and thereby whatever might be the simple power of any press, its advance could only be at the rate allowed by the controlling wedges. He feared that such an apparatus could not be introduced to the presses in the dock without its being made somewhat complex; but, nevertheless, he called attention to it, as a means by which the want of uniformity of load on the presses might be overcome.

He would now say a few words on the subject of floating docks, which the Author indicated as proper objects of comparison with his system. The Author had referred to the failure of several floating docks, but he thought it would be found the failure had been confined to the American sectional dock. To Mr. Bramwell's mind, the failure of these docks was clearly to be traced to two defective points in their design, and to their having been built of wood. The error in design was, first, the making them in sections unconnected by any girder; secondly, the absence of proper water-tight bulkheads. The first error caused the ships to be strained, the second produced the liability to turn over while in the act of lifting the ships, but nothing was easier than to diminish to an insignificant amount this tendency. As by the introduction of a few water-tight bulkheads the tendency to turn over, caused by any accidental inclination of the dock having sent the water contained in it to one side, would be diminished, so as to have no practical importance; the decrease of the tendency would be in a very rapid ratio, that was to say, it would be in the ratio of the square of the number of chambers into which the dock was divided by bulkheads; so that a dock divided by three bulkheads into four chambers would only have $\frac{1}{16}$th the tendency to turn over, that a dock would have in which there were not any bulkheads.

He would, in conclusion, say a few words on a floating dock which was now being constructed from his designs for St. Thomas's in the West Indies; and he begged leave to refer to it, because the Author had said in effect that all floating docks were bad and unsafe things. Mr. Bramwell could not concur in this opinion, and he thought it would be a matter of regret, if a class of docks, which could be used wherever there was water enough to float them, and which were wholly independent of the nature of the bottom, and might therefore possess peculiar advantages in certain weathers, were to be stigmatized as bad and unsafe unless they really deserved that character, which he hoped to convince the meeting they did not. The dock he now alluded to was made of wrought iron, and was 300 feet long by 100 feet wide, and the bottom part was 9 feet 6 inches deep; this bottom was, for convenience of manufacture and repair, made in six separate pontoons; each pontoon extended from side to side of the dock, and was in breadth 50 feet, or $\frac{1}{6}$th of the length of the dock. Inside the pontoons there were a proper number of water-tight bulkheads and a due system of trussing, to distribute the weight of the vessel. Upon the pontoons at the sides of the dock were two girders: these were lattice girders, of about 35 feet high, and sufficiently strong to transmit the surplus floating power of the end pontoons to the assistance of the more heavily loaded central pontoons, and in this way it was believed the fundamental points of keeping all strain off the vessel had been arrived at.

In order to prevent the dock from tilting out of level while lifting a vessel, there were smaller pontoons, or floats, which were contained within the open work of the side girders, and the position of which, in relation to the dock as it rose, was maintained by suitable machinery. He had preferred trussed girders to the ordinary close sides of a box dock for several reasons: one was, that greater strength was got for the same amount of metal; another was, that the open side afforded good ventilation, a most important point in a tropical climate; and another was, that the open girders, when immersed, displaced but little water, whereas the closed sides of a box dock displaced several thousand tons, which had to be overcome by the admission of that extra weight of water into the dock, all of which had afterwards to be pumped out. For these reasons he had preferred the open girders, and had employed the adjustable floats to play the same part in preserving the level of the dock, while being raised or lowered, that the closed sides effected in the box dock. The adjustable float, in fact, represented just that portion of the close side which, from time to time, was at the surface of the water. In using this dock the water would be admitted into the pontoons, which would cause the dock to rush past the floats which would remain on the surface; then the vessel would be drawn over the keel blocks, the water be pumped out, and the float apparatus worked, so that as the dock rose the floats would still remain at the surface, the bilge shores being brought to act on the vessel as soon as her weight was fairly on the keel floats. He thought that this dock and the box dock were, when properly constructed, absolutely safe, and that they would put far less strain on a ship when docked, than would be put on by the Hydraulic Lift Dock as now constructed.

Mr. ABERNETHY, while admitting the great ingenuity which had been displayed by the Author and the other Engineers who had advised with him relative to the construction of the hydraulic dock at the Victoria Docks, was, nevertheless, somewhat at issue with him in the conclusion, that this description of dock was likely to become of universal application; on the contrary, he thought the Hydraulic Lift would be adopted only in exceptional cases. In the Paper, the Hydraulic Lift had been compared with the graving dock system generally, and also with floating docks; and the subjects of comparison instituted were, first, the question of economy, and secondly, certain advantages which were claimed for the Hydraulic Lift. He was at a loss how to institute a fair comparison from the information contained in the Paper, because the Author had selected, in respect of the economy of the question, one of the most recent docks constructed at Portsmouth in connection with the national dockyard at that place. The dimensions of that dock, and the quantity of stone and other material used in it were given, but not the cost. As far as economy was concerned, the Author could hardly have selected a more costly example; because the graving docks in connection with the Government naval establishments were generally built entirely of finely dressed granite ashlar, throughout the whole of their parts, the whole system of construction being of the most expensive character; and it was not therefore a fair subject of comparison with the Hydraulic Lift system; yet it would seem, from these examples, the Author had arrived at the conclusion, that the graving dock system must of necessity be more costly, and, in many cases, even impracticable. But the cost of the Hydraulic Lift had been £66,705 for the machinery, and £21,427 for the masonry and works connected with the lift, making a total cost of £88,132; the results of which, up to the present time, had been to provide seven pontoons of an aggregate length of 1,496 feet.

Mr. Abernethy had, during late years, constructed a number of graving docks at present in use, and proved to be very effective. Several of them possessed, it was true, advantages in respect of site, but there were numerous sites as favourable in all parts of the kingdom. He would, in the first place, allude to the graving docks on the river Mersey, in the red sandstone rock. The dimensions of five docks at Birkenhead, which he had constructed years ago, were as follows: No. 1, 300 feet long, 35 feet wide at the floor, and 18 feet 3 inches of water over the sill at ordinary spring tides; No. 2, 200 feet long, 40 feet wide, and 18 feet 3 inches of water over the sill; No. 3, 400 feet long, 64 feet 6 inches wide, and 22 feet 3 inches of water over the sill; No. 4, 440 feet long, 70 feet 9 inches wide, and 26 feet of water over the sill; No. 5, 350 feet long and 69 feet wide, and depth of water over the sill 22 feet 3 inches—making a total length of docks of 1,690 feet, which had been constructed at a cost of £86,000. Those were instances of graving docks in a favourable site, hewn out of the solid sandstone rock. He had also recently constructed two other docks at Falmouth, of the dimensions respectively of 350 feet by 51 feet, and 15 feet 6 inches of water over the sill, and 400 feet by 66 feet, and 17 feet 6 inches of water over the sill: making a total length of dock of 750 feet, at a cost of £29,000. In the construction of these latter docks, a considerable amount of pumping was necessary, in consequence of the open character of the rock. Then again on the question of economy, it was obviously impracticable to carry out the Hydraulic Lift system near the existing London Docks, on account of the large area occupied; it would be an expensive item to secure such an extent as 26 acres, the area occupied in connection with the Hydraulic Lift at the Victoria Docks.

The advantages claimed for Hydraulic Lifts over the existing graving docks, beyond the question of economy, were—first, freedom from strain to the vessels docked, arising from the elasticity of the pontoons. He was not a shipwright, but he apprehended that the element of elasticity would not be regarded by shipwrights as an advantage; and he thought the rigid floor of a graving dock was to be preferred. It would, he thought, be a dangerous experiment to place a crazy old ship on an elastic bearing. Another advantage claimed for the pontoon system was the peculiar mode in which the vessel was blocked. The same mode had for a long period been adopted in the ordinary patent slip, viz., by bilge and slide blocks. That was as much a matter of necessity in the case of patent slips, as it was on this system; but it was not a matter of necessity in ordinary graving docks. As a general rule, the vessel rested on the keel blocks, and was shored from the sides; but bilge blocks if necessary could as easily be provided on the floor of a graving dock as on a pontoon or patent slip. A great advantage claimed for this mode of blocking, was the replacing the pressure of the water on the outside of the vessel. Now, he thought, very extraordinary blocking was required accurately to represent the pressure of water on the outside of a vessel. It was also stated in the Paper that the displacement of a vessel was equivalent to the weight of each particular section. That was to say, that if a vessel was divided into sections, the displacement was equivalent to the weight of each particular section. He apprehended the displacement was equivalent to the form, capacity, and weight of the vessel as a whole, and not to any particular section. It was further stated, that in the case of a vessel resting on keel blocks, the weight was nearly equally distributed over the whole keel; that, he thought, was erroneous, as the weight would be due to the particular section of the vessel resting on the blocks.

With regard to floating docks, he agreed that such docks could be constructed to dock vessels with perfect safety, and he felt certain, that floating docks would give a more profitable return, and could be worked with greater economy than hydraulic lifts occupying, as suggested, an entire pontoon for the accommodation of a single vessel at a time. One objection made to graving docks was, that on placing a vessel in dock, resting on the keel, a great length of shoring was required; and in the case of the Mersey docks he had adopted means to obviate that difficulty. At certain portions of the dock, he had upright piers in the place of the altar steps, so that a vessel could be brought in between those upright piers, and moored directly over the keel-blocks. Short shores only were required to keep her *in situ*, and those shores might be worked by machinery, so as to be adjusted immediately the vessel was on the keel-blocks. That system of piers had been adopted by him at all the docks at Birkenhead, eleven in number, and also at the two docks at Falmouth, to which he had referred. There could be no doubt, that in regard to vessels of the largest class, such as the 'Warrior,' which had a height of about 40 feet from keel to deck, it would be exceedingly dangerous to risk such vessels on pontoons merely blocked under the bilges, without horizontal shores at the sides. Therefore, he thought if pontoons were ever applied to that class of ships, it would be necessary to have side pontoons, or side frames upon the horizontal pontoons, and when that was the case, the cost of the whole would equal that of a floating dock of the same capacity. As a further use to which pontoons might be applied, the Author had pointed out the opportunities for transporting vessels on them for a considerable distance, as for instance, across the Isthmus of Suez, if the canal were ever cut; but it was quite obvious that it would be impossible to move a large ship any considerable distance on a pontoon with her masts and rigging standing and exposed to the action of the wind. In the instance given in the Paper of such transport, the pontoon, with the ship on it, made so much leeway as to sink herself in a short time with the vessel upon her. It was fortunate this took place in shallow water, instead of in the Victoria Dock itself.

Another point, was the economical working of the existing graving docks as compared with the pontoons; as in the case of repairs to steamers, taking out the boilers, machinery, &c., and putting them in again. When vessels were placed on pontoons, it was a very costly operation, either to erect staging to the level of the deck of the ship, or to lift the boilers, or other heavy weights from the ground, and then to lower them into the vessel; whereas, by means of a powerful crane, placed on such piers as he had provided in his graving docks, the boilers, or other heavy materials, could be removed from the ship, and replaced with the greatest facility. As regarded shoring in graving docks, it could be done in any position, but not so under the pontoon arrangement. While stating thus broadly his view, that this form of dock could be used only in exceptional cases, and not as a general rule, he was at the same time convinced in many positions it would prove successful, as in a tideless sea, or where the physical difficulties were so great as not to warrant the expenditure necessary for constructing the ordinary graving dock. In such a locality as the Victoria Docks, where peculiar facilities were at hand, he thought the hydraulic system was admirably adapted for its purpose; but he repeated, that he thought it must be considered altogether as exceptional.

Mr. VIGNOLES said, the history of docks having been touched upon in the Paper, he would state—as the fact had not been mentioned—that he believed the first instance of the employment of a floating dock occurred about the time of Peter the Great, in the estuary or Bay of Cronstadt, where a North-country captain, wishing to repair his vessel, found an old hulk floating in the bay, upon which he had permission to operate; and he arranged means of letting in, and pumping out the water, so as to form a floating dock, on which to carry out the required repairs to his ship. The name of that old hulk was the 'Camel,' and to the present day a contrivance of that kind was understood by the term 'camel,' which consisted of a rough wooden box, from which the water could be discharged to raise it up, and into which water could be introduced to sink it again. With regard to the invention now under discussion, he thought it was one of the most ingenious contrivances that had appeared for many years. He thought it was applicable in more instances than had been generally admitted, and he thought, the comparison of the expenses of the system with those of graving docks on other systems was quite fallacious. Every invention must be applied to its own particular case; and there were many cases in which this invention could be applied, both abroad and at home, with great advantage.

Mr. W. R. **Kinipple** had watched the progress of these pontoon docks with interest, and thought that great credit was due to the Author for the perfect way in which he had brought hydraulic lifts to bear so successfully upon such enormous weights. The pontoons were, however, somewhat defective, as it was impossible to render them perfectly rigid, without using such a quantity of material as would render them useless. When a pontoon was 300 feet in length, and only 6 feet in depth (which was in the proportion of only 1 to 50), to make it rigid so much metal must be inserted as to sacrifice altogether its floating powers. He remembered seeing one of the longest pontoons, which had, with a ship on it, a deflection of 7 inches or 8 inches out of the straight line. Reference had been made to the pontoon sunk at the London Docks, with which he had had to do. He believed the construction of that pontoon to have been perfect, although it had failed at present. The side girders were 180 feet long, 17 feet deep, and 3 feet wide. A ship might be put upon the deck between the girders without injury to her straight line. He attributed the sinking of that pontoon chiefly to the want of compartments and stiffeners to the bottom plates, between the cross girders, which were 8 feet apart. She was built like a long, flat tea-board. The water went in at one end, and there was a consequent depression of that end. This caused an almost instantaneous rush and accumulation of water to one spot, the parallels gave way under the violent strain thereby produced, and the pontoon went down rapidly at one end, whilst the other was some hours in sinking. Pumping at the rate of 66 tons per minute, had not the slightest effect in reducing the water; and it was not until this great pumping power had been found useless, that forcing air down had been resorted to, when her deck was blown off. With regard to the pontoon docks in these two instances, it seemed to him a great waste of money to construct them in a tidal river, in order to do artificially, that which could be done naturally by the rise and fall of the tide. He had lately finished a dock at Limehouse called the Limekiln Dock; it was 355 feet long, 55 feet wide on the floor, 53 feet at the entrance, and 20 feet of water over the sill. The outer apron was laid in Portland cement, the entrance was of brick, the sides and bottom of timber and concrete, and the cost had been only £17,000. There were, at the present time, two vessels in that dock of the aggregate tonnage of 3,000 tons.

Mr. A. M. **Rendel** said, his responsibility in regard to the pontoon which was now lying at the bottom of the London Docks was small. Messrs. Rose and Crowder, who worked, for some time, the hydraulic lift at the Victoria Docks, proposed, to the London Dock Company, to lease a part of the eastern dock, and to build a pontoon there on their principle. The proposal was referred to him; he reported favourably on it, and the pontoon was constructed. He heard nothing more of the matter till he was informed, that the pontoon had gone down head foremost to the bottom of the dock. On looking into the plan of the pontoon, he found that it had no bulkheads; consequently, the water, when let into it, caused a violent oscillation; and the parallels, by which it should have been steadied, being constructed in a most inefficient manner, were torn from the ground, and the whole structure sank. The fact that the water could not be reduced by pumping led him to think that the caulking of the decks was blown out; he did not think there was a hole in her bottom. On the general subject he would say, there could be no question that the hydraulic lifts were very useful in their actual situation; but he was not prepared to admit their applicability to all docks. For instance, at the London Docks, he apprehended that land alone would cost about £40,000 per acre. He would mention that he had completed a dry dock at Leith, 400 feet long, 84 feet wide, with 24 feet 6 inches of water on the sill, the cost of which, including caisson, engine-house, pumps, and all complete, had been under £40,000. The engines worked up to 100 H.P., and were applied to a large Appold pump. So long as ordinary docks could be constructed at that cost, he did not think docks of the character under discussion would be again constructed in this country.

Mr. A. **Giles** thought many advantages would attend the application of this beautiful invention in ports such as London and Liverpool, and perhaps Hull; but, apart from those ports, he considered there were no others where docks upon this large scale were called for. There was one fact to be remarked, that when a vessel was placed upon this pontoon, she had the advantages of light and air which she could not have in an ordinary graving dock; at the same time the operation of lifting the vessel on the pontoon was attended, he thought, with certain disadvantages. In removing and replacing the boilers, he did not think the objection which had been stated applied, because the boilers were not generally put on board while the vessel was in a dry dock; at the same time, in matters of general repairs, it might be a disadvantage to have to raise materials to a height of 30 feet, or 40 feet, instead of their being supplied from the level of the deck. With regard to the shoring of ships on the pontoons, some merit was claimed for the absence of strain upon the ship, by the putting in of the bilge blocks. He did not know what there was to prevent the same sort of shores being used in ordinary dry docks. The fact, however, that bilge blocks were not used seemed to be good evidence that such shores were not wanted, and, during an experience of twenty years, in docking vessels of all sizes, up to 4,000 tons, he had never yet heard of an injury having arisen from the want of bilge blocks. The position of a vessel on bilge blocks was similar to that of a vessel on the beach, and there was great objection to the beaching of steam vessels from their liability to strain. He thought there must be some advantage in grounding upon the keel, and in putting in, when the ship touched the blocks, horizontal shores against the altars, for the purpose of keeping her upright on her keel. As the water was pumped out of the dock, raking shores were added. Comparing the statistics supplied by the Author with those of the Southampton Docks, it appeared, that at the Victoria Docks 1,055 vessels of an aggregate tonnage of 712,380 tons had been docked by these lifts in seven years. At Southampton, during the last seven years, 693 vessels had been docked of an aggregate tonnage of 965,000 tons. The average tonnage of the vessels docked by the pontoon system was only 675 tons per ship, while the average of the vessels docked at Southampton was 1,400 tons per ship. With that experience, if no damage had been sustained from the absence of the bilge blocks, it might be safely inferred that they were not necessary. As to the cost of docking vessels, the Author had given it at £3 per vessel, for putting on the pontoon, pumping, and lifting: if that calculation was correct, the system at the Victoria Docks had a great advantage over that at Southampton in respect of the cost of docking. His experience was, and he could vouch for the correctness of the figures, that the total expense of docking, including pumping, labour, and repairs was, on an average, £13 per ship, but that was for ships of double the average size of those docked by the Thames Graving Dock Company. It was evident that there must be some other element of expense which had not been reckoned. The charges for docking ships on the patent lift were about the same as at Southampton, viz., 6*d.* per ton for docking, and 1*d.* per ton per week, for the use of the pontoon. For a 1,000 ton ship, the charge for docking at Southampton was £25, and the rate for the use of the dock was in about the same proportion as for the use of the pontoons. With those 965,000 tons docked at Southampton during the last seven years, the Company had earned £39,000 and the expenses had been about £8,000; the average amount paid by each ship being £55, and the expenses £13. If, therefore, the charges were practically the same in both cases, and the expenses so much less in the hydraulic lift system, how was it that the Company had been such a commercial failure? These figures, if correct, ought to have shown a good profit. With regard to the first cost of the hydraulic lift docks, it was stated to be £88,000; but it must be borne in mind that sum did not include the cost of land, engineering, patent rights, and other things, which were usually included in the capital cost. The capital of the Graving Dock Establishment at Southampton was taken at £150,000; but, he believed, interest had been charged to capital to swell it to that amount, for this was considerably beyond the actual cost of the docks. If, by the system under discussion, the sum of £88,000 gave a capability of docking seven ships at a time, he confessed that, by the ordinary system, with the same number of docks, it could not be done at the same price. He then explained a drawing showing the sections of two docks which he had lately constructed at Bow Creek. In the larger one, he had drawn the sections of two ships, one being the 'Warrior,' of 6,000 tons, and the other the paddle steamer 'Napoleon Third,' of 4,000 tons; neither vessel could be docked by the hydraulic lift as constructed. These docks were placed on a part of the Thames where the foundations were notoriously deep; the cost of the two docks, including coffer-dams, pumping power, caissons, and everything complete, was £85,000. One was 400 feet long, with a 64 feet opening, and 24 feet of water over the sill. The other was 300 feet long, 46 feet opening, and 21 feet of water over the sill. If he were asked to design a system of docks, one of which should accommodate vessels of 6,000 tons or 7,000 tons, and the others, vessels of smaller size, he believed he could build six or seven docks for £150,000; but if the hydraulic lift and seven pontoons, one of which should be capable of carrying the 'Warrior,' could be constructed for £88,000, that system would surpass any other he knew of in point of economy. A system of docks, sufficient for almost any port, comprising six docks of various sizes (the largest of which was capable of docking the 'Warrior'), including six acres of land, with pumps and every necessary appliance, could be completed for £150,000.

As to the capability of doing work in hydraulic docks compared with ordinary docks, the time occupied in lifting a ship had been given as twenty-five minutes. That could not, however, be meant to include the whole operation of putting a ship on the pontoon, lifting, and moving her into her berth; for he understood that, practically, the time actually occupied in preparing a ship for the pontoon, taking her lines, preparing the bilge blocks, floating her into position, sinking the pontoon, lifting the ship, and getting her into berth, occupied about four and a half hours; whilst the operation of undocking occupied about one hour and a half. If that were so, the capability of work on one lift (though there might be fourteen pontoons or fifteen pontoons), was limited. By the ordinary system, one ship could be docked at each tide; but in the large dock at Southampton, which had been constructed twelve years, more had been accomplished. Upon one occasion, three large ships, each of more than 2,000 tons, required to be docked in a hurry; two were docked and undocked, and the third was docked and placed on the blocks between daylight and dark. He therefore believed the capability of that dock was almost as great as that of one lift.

Mr. JOHN HEPPEL said, having had the advantage of being associated in the preparation of the plans for this work, a few words from him might not be out of place. He necessarily became intimately acquainted with all the mechanical details of the construction, and the considerations which led to the adoption of them. To this part of the question he proposed strictly to confine himself, leaving the commercial and general aspects of the case to those who were better qualified than himself to deal with them. In doing this, however, he might perhaps be anticipating what would be better left to the Author; but he could not help thinking, it would be satisfactory to that gentleman to know, that those who concurred with him so many years ago in the views which he took concurred with him still, and were able to give some reasons for that concurrence.

Many observations had been made as to the flexibility of the pontoons in connection with these operations; and great doubts had been expressed whether some disadvantages to the vessels raised did not result from this flexibility. This was a subject which was carefully discussed at the time the apparatus was designed, although no great point was made of it; for even if the pontoons had been rigid, he did not remember that either the Author or himself thought any great harm would result. But a certain amount of flexibility appeared rather advantageous than otherwise, and he thought, reasons might be shown for it. It had been admitted, that if the vessel itself possessed the quality of rigidity in a sufficient degree, the rigidity of the pontoon became comparatively unimportant. He agreed in that view, and he thought, therefore, it was not necessary to say much about the raising of iron vessels, because it was known that all those vessels possessed such an amount of rigidity, that when once placed on the pontoon, however flexible the latter might be, the rigidity of the two together would prevent any deflection which could possibly be considered injurious. That being the case, he thought the small amount of flexibility the pontoon possessed was an advantage, because it acted upon every wedge and block as a spring to keep it fairly up to its work. In fact, as compared to a rigid floor, it stood in the same kind of relation, as a spring mattress to a deal board.

A strong point was however made with respect to wooden vessels, and an instance was adduced of an old crazy vessel which had a considerable amount of 'hogging.' He would even admit, for the sake of argument, that it might be considered desirable to bring such a vessel to a straight keel, though he thought that was admitting a great deal; but if this was desirable, he could hardly conceive anything better calculated to straighten the keel, without injury, than the apparatus in question.

To follow the steps of the operation: the vessel came upon the lift, the keel blocks having been prepared approximately to correspond with the curve of the keel when afloat, the vessel, having taken the keel blocks, the lifting began. As this went on, the slight difference in the distribution of the force between the weight (which was more in the middle than at the ends) and the lifting force, which was uniformly distributed, produced an action tending to deflect the pontoon, to a certain extent, and that tended to bring the keel nearer to a straight line, and so far to accomplish the desideratum. If any strain, or symptom of strain manifested itself, this apparatus gave instant means of obviating it, because, by cutting off a pair of the presses, the lifting power might be brought to correspond with the distribution of the weight to be lifted; so that, by the time the vessel was lifted out of the water its keel might be, by a simple process of manipulating the presses, adjusted to any line required; and that was done not by any violent process, as in a dry dock, where the vessel would be left to settle at once to a straight line, but was effected by means that were always under the most perfect control. When the pontoon was lowered into the water, after having been emptied, the same thing which was done by manipulating the presses, might be done by letting in water in the required proportion into the compartments, by which the lifting power of the pontoon might be brought into perfect adjustment with the weight above it. Nothing was more calculated to deal with the requirements of the kind noticed than this apparatus; and if it were correct, as had been stated, that some vessels had suffered injury from deflection (and an instance had been given of a hogged vessel which when set afloat on the pontoon was found to be deflected the other way), he could not help thinking it must have been from some want of judicious management in the operation; because he could not conceive that anything inherent in the apparatus itself could lead to such a result; on the contrary, he thought the Author had claimed for the machinery, in this respect, less applicability to the requirements of the case than was due to it.

He would not go into the question of comparison between this mode of lifting vessels and the system pursued in dry docks, because everything that could be said on that subject had been already very clearly stated. The matter had been put in a very fair point of view, because a comparison had been drawn between pontoons of this kind and an equal number of graving docks. A few observations of a qualifying character had been added, but it was a fair comparison; and he understood it to be admitted, that a series of dry docks, equal in number to the pontoons of this lift, could not be established for the same amount of expenditure. With regard to floating docks, a great number of examples had been instanced. Those which could only accommodate one vessel at a time could not be put in comparison with the apparatus under discussion, in respect of the amount of accommodation. A model had been placed on the table, in which, by a system of railways and cradles, something like the same results were proposed to be accomplished as by the present apparatus. He was far from being disposed to say that the proposed plan was not a good one; but he thought, it must be obvious that dragging a vessel about upon cradles must expose it to greater strains than the smooth and easy way of dealing with it by the hydraulic lift. However, it might be said, with regard to such a lifting dock, it would be easy to use it in connection with pontoons, in the same way as the hydraulic lift; and in that case the Author of the Paper would be entitled to the credit of the most original and valuable portion of it; but even then it would be inferior. He spoke under correction; but he hardly imagined, that a floating dock of that kind, having equal lifting power with the hydraulic presses at the Victoria Docks, could weigh less than 2,000 tons. If his conjecture was correct, it was obvious, that for every vessel, large or small, lifted with that apparatus, a dead weight of 2,000 tons was being lifted with it, instead of less than 700 tons at a maximum, which was capable of reduction in proportion to the load to be raised. He therefore thought the floating dock, even in the best form, must be inferior, in respect of efficiency, and economy of power, to that which was now the subject of discussion.

There was one other point. It was admitted, that for a fixed water-level, the Hydraulic Lift was not an inconvenient apparatus;

but it had been asserted that its use would be confined to exceptional cases. He only wished to draw attention to the fact, that in this case, there was a free choice between the Victoria Docks and the tideway of the Thames, and it was considered, on all accounts, more desirable to establish the graving dock in connection with the former, than with the latter, the greater facility of communication with the dock being considered of more value than the mechanical power derived from the tide, and he thought, that similar considerations would prevail in most cases where there was a similar choice. But if it were not so, and if the use of this system was to be confined to cases of fixed, or nearly fixed water level, there would still be the Baltic, the Mediterranean, and nearly all the ports on the Pacific; and he thought, perhaps, the Author would be satisfied with that to begin with. He had recently seen this apparatus, and he was struck with the remarkably good condition in which it was kept. Every part was in good working order, and in charge of highly intelligent people. He thought the mechanical results had been such as to place the professional reputation of the inventor beyond all danger; and he hoped the commercial results that would follow would be such as to remunerate those individuals who had ventured to try, what was considered at the time, a very bold experiment.

Mr. J. B. Redman said, it must be acknowledged, that the thanks of the commercial community were due to the Author for this attempt to facilitate the raising of vessels in the port of London. Some years ago he placed a Paper before the Institution on the variety in direction of the different Metropolitan dry docks, and he was bound to say that the variety in direction, in reference to the tideway, was as greatly exemplified in the mode of construction of the various docks upon the Thames. Whether the Thames—a tidal river, which had hitherto done what was now attempted by means of this most ingenious apparatus—was the best site, remained to be proved by experience. Undoubtedly, a graving dock, at the end of the Victoria Docks, might have been drained by the action of the tide, and the dock might have been arranged as others had been on the Thames. Certainly the element of cost was one of great importance; but, he could not help thinking, a comparison of the cost of this system, with that of the docks at some of the outports where the formation was different to the valley of the Thames, must be to a great extent illusory. The former were artificial docks in all respects, but the geological formation of the districts was so different, as to afford no comparison on the question of expense with the port of London, to which the system of the Author had been applied.

The Trafalgar Graving Dock, at the west end of Woolwich Dockyard, was constructed for the Admiralty, by the late Mr. James

Walker, after the failure of a prior experiment, by Mr. Ranger, of a dock of concrete. That dock was never free from a percolation of water through the sand and natural substratum; and the invert blew up. With that experience before the designing of the present dock, it was natural that every care should be taken that the work should be sound. When he said the pit of that dock was 40 feet from the surface, it was clear it was not comparable with a dock like that at Sunderland, where the rock was so close to the surface, that the work involved did not commence before an amount had been expended which came to more than 30 per cent., or 40 per cent. of the total expenditure incurred in a case like that at Woolwich, where there was 9 feet of concrete, a floor of 18-inch brickwork set in pozzolana mortar, and an invert of solid granite 3 feet 6 inches thick. The entire surface of the dock was faced with granite. The section of the dock was parallel to that of the 'Trafalgar,' a 120 gunship, and of course the work was carried out in the most costly manner. The early timber docks of London, including the old Pitcher's Dock at Blackwall, which was subsequently rebuilt by the present owners (the Messrs. Soames), were built entirely of timber, and of clay puddle. The bottom was piled, over the entire surface, the larger number of piles being placed in the direction of the line of the keel. The old Pitcher's Dock had failed in a similar way to that at Woolwich, from the hydrostatic pressure. Another reason why the comparison of cost would hardly hold good was, that almost all the London docks, with few exceptions, were dry docks in two senses of the word; they were not only dry when the gates were shut and the vessel was docked, but any amount of leakage which accumulated in the dock was drawn away at low water. There was never any attempt made to resist the hydrostatic pressure, but the water was led away to the engine-well and taken away by steam power; so that such docks as these were not comparable with the deep-water dock at the mouth of the Lea. He would say generally (having taken the trouble to classify these early docks, taking the internal capacity, the length, breadth, and depth, *i. e.*, the cubical contents), that he found the cost had been from 12*s.* to 15*s.* and £1 per yard cube of the internal sectional capacity of the dock, while the figures stated for the docks at Southampton would work out a cost of £1 17*s.* 6*d.* to £1 18*s.* 6*d.* per cubic yard of internal capacity, and the value of the dock at Woolwich was no less than £4 10*s.* per yard cube. The dock at Boston, United States, by published documents, was about equivalent to the latter value. He thought if the eight pontoons at the Victoria Docks were assumed to represent eight timber docks of equivalent superficial dimensions by the depth, with the 18-feet draught over the hoisting gear, the result, taking the

Author's figure of £80,000, would give a value for that capacity of something equivalent to the timber-dock value; that was to say, the eight docks, by the mean length and breadth given with the 3 feet above, would be worth about 12*s.* per cubic yard. If there had been an outlay there of double that sum, then the value would be double; and if, again, the outlay had been £200,000, the value would be 25*s.* per cubic yard. Taking the cheapest value, the comparison was not favourable to the Southampton Docks. There was an example at Sunderland, frequently quoted, in which he believed the value and the dimensions gave about 27*s.* 6*d.* per cubic yard of internal capacity. Some surprise had been expressed, that no notice had been made of the hydrostatic screw dock at New York: it was equally surprising, he thought, that no notice had been taken of the patent of John Evans, of New York, which was described, very minutely, in the first number of Weale's 'Quarterly Papers' in 1845, as consisting of a series of cylinders and presses, precisely similar in principle to the Bramah Press, and connected by vertical chains to the ends of the transverse beams, underneath the pontoon gridiron. When the enormous increase of the trade of the port of London was considered, and the efforts which had been made to develop the commerce, the thanks of the commercial community were due to the Author. He had, however, had one advantage which no other Engineer, acting for a public Company, had previously possessed. The Victoria Docks was the first Company that obtained powers to construct a graving dock. The old Wapping Dock Act contained clauses for graving docks, but the ship-building interest was too powerful in that day, and those clauses were struck out in every Dock Act afterwards. Whether a dock Company could build and repair ships with the same expedition as private builders, was another question; but he felt convinced, from the experience of some years, that that exclusive principle, together with the tyranny of trade unions amongst shipwrights, had, to a great extent, driven the old shipbuilding trade from the port of London. The late Mr. Duncan Dunbar had frequently told him, that on the Tyne and other outports, he could get his ships built, with lower masts and standing rigging, at the same price as that which he paid for the hull alone, in the port of London.

Mr. JOHN MURRAY remarked, that in the discussion which had taken place, he considered they had not arrived at the full cost of this pontoon dock. Mr. Clark had given the expense of the excavations, the coffer-dams, and other details; but he had not alluded to the land occupied by the works—some 26 acres in extent, 16 of which were water, and ought to be added to the sum of £88,000. A comparison between this pontoon dock and ordinary dry docks of masonry or brickwork might fairly form a subject of discussion.

He had ascertained the cost of graving docks in various parts of the country, which, combined with the information already given, might prove useful. Mr. Abernethy had stated that the average cost of the seven docks at Birkenhead and the two at Falmouth was about £14,000 or £15,000. The dock at Holyhead, constructed by Mr. Telford, cost £14,419; that at Dundee, £26,000; that at Belfast, in 1840, £19,362; and the dock built by himself at Sunderland, including pumps, engine, and enclosure, cost £16,185. Taking an average of the four docks, it amounted to £18,990. Those docks were all nearly of the same class, viz., from 240 feet to 320 feet long, and 70 feet across at the coping, and 36 feet at the bottom, and they were each capable of admitting two ordinary vessels, or one large ship. The dock at Sunderland had altars on the side, with a temporary end, so that it might be lengthened when required. Docks of this kind had been constructed, therefore, at an average cost of £18,000 to £20,000 each. They were all of good masonry and substantial workmanship. But in the port of Sunderland and on the River Tyne docks of a slighter description had been constructed, capable of holding one ship at a time, and at a cost of from £3,000 to £5,000. Besides these, the shipbuilders generally had floating docks alongside of their shipbuilding yards, into which vessels were brought for repairs. One of the earliest of these docks was an old gun-brig cut down for the purpose. The deck and upper works being taken away, moveable gates were placed across her stern, and she was thus changed into a floating dock. The shipbuilders had since constructed other floating docks in the ordinary manner. Docks of a better description, such as those at Liverpool, lined with granite and of a large size, had been constructed at a cost of from £25,000 to £50,000. Another class, capable of admitting men-of-war, had amounted to £100,000 and upwards. But in general a good graving dock of ordinary construction might be said to cost from £15,000 to £20,000, capable of admitting all ordinary vessels, and two at a time of the smaller class; and when once properly constructed they wanted no repairs, and therefore might be called permanent structures. He thought they might well be compared with floating pontoons, admitted separately into one entrance or receptacle, having a great amount of apparatus connected with it, liable to get out of order, and requiring much manipulation, which he considered a more costly affair than a substantial graving dock of the ordinary form.

Mr. G. B. RENNIE said, in reference to a model, which he had placed on the table, that it represented the works constructed at Carthagena, and was designed for the purpose, after the vessels were lifted on the floating-dock, of hauling them ashore by hydraulic presses, or on cradles. The ways were perfectly level, and the amount of power required to haul them on shore might be calculated on the consideration, that the launch-ways of a heavy vessel were made with an incline of $\frac{1}{2}$ inch to the foot, or 1 in 24: so that, about $\frac{1}{24}$th of the weight of the vessel had to be pulled by a hydraulic pump and portable ram. This was not altogether a new idea, for it was in operation at the present time at the arsenal of Pola, on the Adriatic, where there were four lines of horizontal ways, which were used for hauling the vessels on shore. He believed the largest vessel operated upon by this system, was the 'Kaiser,' a screw line-of-battle ship of 84 guns. The floating-dock at Pola was of wood.

With regard to the Hydraulic Lift Graving Dock, he had several times seen vessels lifted, and it seemed to be done with great ease, regularity, and apparent safety. He did not agree with the Author as regarded the flexible pontoons. It seemed to him, if there was flexibility in the pontoons, there must be a strain on the vessel; and it was always desirable to prevent undue strain, as far as possible. However strong a ship might be, there must be some extra strain if it had to support the pontoon in a horizontal position, instead of the pontoon supporting the vessel. With regard to bilge-blocks he might state that it was proposed to use them in the floating-docks at Carthagena and Ferrol. When those docks were designed it was also thought desirable, that breast-shores should be used: for where a heavy vessel began to rest on the keel-blocks, it was difficult, with 25 feet of water under her, to place the bilge-blocks properly to support the vessel and prevent canting. He hoped on a future occasion, when this work had been tried more fully, to describe it in a Paper, before the Institution.

Mr. Scamp exhibited three drawings. The first was a section of the hydraulic lift, provided with shoring-altars for supporting vessels with breast-shores, as in an ordinary dock, showing also a pontoon with shoring-altars, for shoring under a vessel's bilge, precisely as in an ordinary dock; and a midship section of the 'Himalaya,' with the breast-shores, &c., attached.

The second drawing represented an ordinary stone dock (that referred to by the Author in his Paper), showing half midship sections of the 'Bellerophon' and the 'Lord Warden.'

The third represented the side view of a ship, with gauge-marks parallel with the original straight line of keel, for ascertaining precisely the hogging or cambering of the vessel.

Referring to the first drawing, he stated that he considered, by the addition of shoring-altars attached to the lift, and shoring-altars attached to the pontoons, that vessels of the tonnage of the 'Himalaya,' in a sea-going state (4,000 tons), might be safely docked by the lifting-dock, with the additional precautions shown by the section. The shoring-altars attached to the lift were only required for about a third of the midship length of the ship, and only to each alternate column; and though he considered the breast-shores to be absolutely necessary, especially if employed in the war establishments of the Navy, yet no great strain would be brought against them, as it was obvious, that the centre of gravity of the load being placed precisely perpendicular over the centre of support on the keel-blocks, it was only necessary to employ the shores for precisely fitting the space between the side of the ship and the abutment at the altars attached to the dock. The shoring-altars attached to the pontoons were not proposed to be continuous; but to extend to about a third of the midship section, in lengths of about 20 feet, and spaces of about the same lengths alternately, and it was proposed to attach them to such pontoons only as were required for vessels of more than 1,000 tons; vessels of less than that tonnage might be safely docked as at present. The breast-shores being carefully fixed (the keel being only just clear of the blocks), the dock should be lifted sufficiently for the keel to bear on all the blocks; in this position some of the blocks might be drawn under the bilges of large ships, or of those appearing to require them; for small vessels this operation at that time was not necessary. The pontoon might then be lifted, until the keel-blocks were out of the water, and the vessel might, then, be as completely shored, as in an ordinary dock; and such bilge-blocks might be added as might appear to be required. The vessel being completely secured on the pontoon, the breast-shores would be removed, and the vessel might be safely floated away from the dock on the pontoon to a shallow dock, as at the Victoria Docks, or to a wharf, or basin; or for executing extensive repairs, the pontoon might be grounded on a 'gridiron' at a basin wharf.

The docking duties in times of war, for Her Majesty's naval establishments, might be classed under three divisions:

1. Previous to the actual commencement of hostilities.
2. During an action.
3. After an action.

As regarded the preparations, probably every available vessel, certainly those provided with steam power, might have to be commissioned for the service; those already commissioned as well as those taken from the moorings—out of 'ordinary,' as it was called—might require to be docked; until a vessel was in dock, the time that she might require to be there could not be known. For that division of the docking duties, he considered the Hydraulic Lift Dock, with its ten pontoons, or fifteen pontoons, might prove an incalculable advantage, being equal to as many additional docks.

He thought this plan peculiarly adapted for the great naval establishments, particularly in time of war, when all the duties of those establishments had to be carried on with the greatest despatch, and with unerring accuracy, under great pressure. It might probably not be prudent to carry this system to the extent of dealing with ships of war of 10,000 tons, as proposed by the Author of the Paper some years ago, yet it was desirable that the Institution should give an opinion as to that proposition being carried into practice for vessels up to a certain class; he had suggested, that vessels up to 4,000 tons, equipped and in a sea-going state, might safely be docked by the method proposed.

The system of shoring he had described was equally applicable to every form of graving dock. He had submitted the drawing of the two half midship sections, to show that the 'Bellerophon' did not require the bilge-blocks, but that the 'Lord Warden' did require them to a certain extent. That form of support was the best in his experience, and it might be applied to the Hydraulic Lift Dock. It was a matter of great national importance, to determine whether the Author's method of docking ships for repairs, with the additional security proposed by him, was or was not applicable to the war establishments of Her Majesty's Navy; and for arriving at a sound conclusion he considered that the opinion of the Members of this Institution could not fail to afford useful assistance.

There were three establishments which must be greatly taxed in event of war, Portsmouth, Devonport, and Malta. If, by a method of this kind, ships could be docked, and prepared to join the fleet again with great despatch, the advantage might be equal to almost double the number of ships; whereas if ships had to be kept waiting to be docked, the most disastrous consequences might be the result.

He would not hazard a positive opinion that the system of lifts and pontoons was not applicable to ships of a larger class than that which he had suggested, 4,000 tons, but it should be borne in mind, that his suggestions had reference only to the war establishments of the navy; that vessels of the class proposed by him would not cause inconvenience in management; that to one vessel even of such tonnage, many below of smaller tonnage would have to be employed, and might have to be repaired; that the pontoons would not be unreasonably expensive, or occupy unreasonable space; that, for an establishment such as that at Portsmouth, the pontoons might pass from the basin, in which the vessel would be docked, to other basins less occupied; and if a method of the kind proposed should be adopted, the ordinary docks might not be wanted for small vessels, but would be generally available for such ships of the line as would be required to join the fleet with the utmost despatch, when the time for such duties might not admit of being measured by weeks, or days, but by hours and minutes. It should be observed further, that vessels of large tonnage might require to be docked when light, and not in a sea-going state; for such cases 4000 tons would represent a large class of line-of-battle ships.

It had been suggested that vessels 'hogged' or cambered should be put into dock on blocks, in a straight line, and that the keel of a 'hogged' or cambered vessel should fit itself to the straight line by its weight. In this opinion he did not concur, because when the vessel was again in the water and loaded, the original line of keel would certainly be formed. Three gauge marks should be put on the side of a vessel above the water line, parallel with the straight line of keel; these marks being measured from the water line, the amount of hogging or cambering might be ascertained with great facility, and the blocks on the dock might be thereby correctly adjusted.

He had given great attention to the Author's ingenious invention for many years past, with a view of ascertaining to what extent it might be usefully employed at some of the naval establishments; and recently he had given the subject a full and careful consideration. The result was what he had briefly explained, and shown by the section, and this would, in his opinion, provide what he considered to be necessary, and what he had long desired to accomplish. The section was intended to convey the principle only, not the details of his proposition. He did not anticipate that the girders between the points of suspension would, necessarily, require to be increased in length.

Mr. Hawkshaw, Past-President, remarked that this subject, like many others, resolved itself into comparisons of cost between graving docks of different kinds. The cost of a graving dock in one place could not, however, be compared with the cost of another, unless all the circumstances were known. There could be no doubt that the Author's invention, which he had so clearly described, was, as a mechanical apparatus, perfectly successful. It did that which he proposed it should do, and did it well, and machinery which lifted 2,000 tons could, probably, be made to lift 4,000 tons. But there was one remark to be made upon that point, affecting the question of cost. Where a series of repairing docks was required for repairing vessels of different sizes, the access to the whole of which was to be by means of one lift, if the apparatus were to be made powerful enough to lift vessels like the 'Warrior,' the same apparatus would have to be used for lifting the smallest vessels. Admitting the apparatus, mechanically to be perfectly successful, there arose the question of cost. Now that question could not be usefully treated by comparing these docks with those of the Mersey, which were cut out of sandstone, or with docks in other places, where the circumstances might not be the same. It was difficult, therefore, to arrive at useful conclusions on this point. Still there was in this case, what rarely happened in other cases, something like a guiding principle on the question of cost. With respect to the repairing docks, apart from the lifting dock, it was evident, that all that could be saved, was the difference of excavation in these docks compared with the amount of excavation in an ordinary graving dock, due to the difference of their respective depths, bearing in mind, that the repairing docks must be deep enough to float the pontoons laden with the weight of the ships. On the Author's plan, the cost of the gates was also saved. Against that saving there was to be set the cost of the pontoon. Now it did not at present appear that the saving in the repairing docks, adding the pontoon, could be much; in other words, the cost of the pontoon would probably, in many cases at all events, equal the cost of deeper excavation and the gates. In fact the cost of gates and of the deeper excavation and masonry might, in many cases, be less than the cost of the excavation and masonry for these repairing docks, including the cost of the pontoon. At all events, that was the form the calculation must assume. With regard to the lifting dock, it was evident the apparatus for lifting the ship, and the machinery of the rams and steam engines, would, generally speaking, be at least as costly as the cost of pumping apparatus, even in the case of a tideless sea. For in those situations, the entrance to a lifting dock must be made deep enough, not only for the draught of the ship, but also for the additional depth of the pontoon, and of the girders beneath the pontoon. With regard to the question of economy, in cases where there was a large rise and fall of tide, as in the Severn, and where no pumping was consequently required, the ordinary graving dock would often be cheaper than the one under consideration. After all, the question of cost must be considered specially, having regard to all the circumstances in each separate case; and without going into the question in that form, no satisfactory decision could be arrived at.

Mr. F. W. Sheilds said, it would be most desirable to have the means of comparison with as many other docks of a different kind as possible; and with that view it occurred to him to describe a design he had recently made for a floating dock, and to give a few statistics about it which might be useful. It was a design for a dock 270 feet long and 55 feet wide, intended to lift sailing vessels of 2,500 tons, and the weight of wrought iron in it was calculated at 2,650 tons. In that design he did not claim any invention, as many such constructions had been made before; he had simply been guided by the best experience hitherto attained, and he had endeavoured to employ the materials in the most mechanical and economical way. It was natural to compare the system of that dock with the system of pontoons in the Author's dock, and the first point of comparison was the great difference in the depth of a dock of that nature and the depth of a pontoon which carried the vessel in the lifting dock system. The depth of the sides of the floating dock was 40 feet, while in the Victoria dock the depth of the pontoon was only from 5 feet to 7 feet; and if the ordinary girder rule were taken as an approximate guide, viz., that the deflection of each girder was as the square of its depth, there would be found, such an enormous difference in rigidity, as to make it evident that the Author had widely departed from the system hitherto in use, and had fully adopted the system of flexibility, instead of perfect rigidity. The first point to consider was, which of the two systems was most adapted for a vessel which was taken out of the water. There was no doubt that any system which would enable the vessel to assume perfectly the same position when out of water as she assumed when in the water, would be the most perfect system; but that was a difficult thing to attain in practice, and it was much to be doubted, whether the system of flexibility in a pontoon would effect it: and it was difficult to say beforehand, what form the keel of a vessel would assume, if put upon a flexible platform. It had been said, that the line of the keel could be adjusted, by managing the pontoon properly; and that if the keel took a different shape from that which it had when the vessel was water-borne, it could be corrected and rectified by letting water into the different compartments of the pontoon. Now that appeared to be a delicate operation, and if through carelessness, or any other cause, the water happened to be let into the wrong compartment, there might be serious results. On the other hand, with the system of a perfectly rigid dock bottom, the vessel would probably not be got perfectly into the same position in which she was when in the water; but an average result would be obtained, by bringing the keels of all vessels to a straight line when docked; and the line of keel would not be altered to such an extent as to be injurious, unless the ship were a very cranky one indeed; for that reason rigidity in the dock bottom was preferable, in practice, to the system of flexibility.

There was one other point which occurred to him, namely, that if a pontoon were sunk to the bottom of a dock independently of the hydraulic apparatus, then, when the water was simply pumped out of it, the vessel could be raised by the pontoon alone, without the intervention of the hydraulic lift; and thus it would also be possible to diminish the depth of the dock, as the space in the bottom of the lifting-dock, which was occupied by the cross girders, would not then be required. It seemed, at first sight, that it would be practicable to work a series of pontoons in that way, and that, as all the lifting apparatus would be thus dispensed with, it would be a simpler system; but he had no doubt, there were corresponding advantages which induced the adoption of the double system of lift and pontoons, and he mentioned the subject, in order to ask the Author to give some information upon it.

It had been said, rather in the way of objection to the system at the Victoria Docks, that it was commercially unsuccessful until the repairing shops were established. It seemed to him, with regard to such docks in London, that there was such an amount of competition from the graving docks, that if the Company did not afford the shipping public every possible convenience, they could hardly expect to get the amount of trade, which would be secured by rival establishments, and it was hardly fair to compare a dock in London without that accommodation for repairs, with a dock at Southampton, which was exposed to no opposition or rivalry, and which without a repairing establishment, might make a fair return on its capital; while a similar dock in London, where there was a great deal of opposition, would get little business.

Mr. ABERNETHY said, the question of economy had been dealt with only as regarded first cost; but the cost of working after construction must not be lost sight of, having regard to the various operations to be performed in graving docks. A common operation in a graving dock was the cutting of a vessel in two, and lengthening her. He would like to know how that operation could be performed upon a pontoon, more especially if it were flexible. There were several practical shipbuilders present, who would, no doubt, be able to give information as to the operations to be performed in the repairs of shipping, more particularly of steamers, and as to the advantages, or disadvantages which an ordinary graving dock had, as compared with the pontoon system.

Mr. G. H. PHIPPS said, it must be clear to all, that before approving of the description of dock which was the subject of discussion, they ought to be satisfied of its perfect mechanical efficiency. He could say, from several visits he had made to that dock, he was quite satisfied with its mechanical action, which was in all respects efficient and satisfactory; that the raising was done in a sufficiently short time; that the pontoons were readily floated into shallow water, and into their berths, and that the vessels were perfectly steady and firm upon the pontoons, whilst being repaired.

The next point he would touch upon was with regard to the effect, advantageous, or disadvantageous, of elasticity in the pontoon itself. He considered, that practically the elasticity was too minute to be of any consequence, either one way or the other, and this was proved by the absence of any ill effects on coppered vessels. The buckling up of the copper was a good indication of a vessel losing her sheer, or becoming 'hogged;' but no such effect had been detected, so far as he was informed; and therefore, the elasticity of the pontoon might be safely neglected in the consideration of this subject.

With regard to the comparison between this and other descriptions of graving docks; the only description of dock with which it could be fairly compared was that where the graving docks opened out of basins, wherein the water was maintained at the level of high water. No doubt the docks in the Thames—Pitcher's graving dock, and others of that class—were very cheaply constructed, but these were only suited to letting vessels in and out at particular states of the tide, and did not apply to the exigencies of the trade as it now existed. Taking a comparison between the hydraulic lift graving dock and docks of the ordinary kind entering out of basins, as above described, one of the advantages of this dock appeared to be the facility and economy, with which the docking accommodation could be increased. Supposing one ordinary graving dock to cost, in the above situation, about £45,000, and as a very full estimate, that a Hydraulic Lift Dock, with one large pontoon, cost about the same money (in both cases dams, engines, and all other expenses being included), then, by the supply of one additional pontoon, with berth for the same, at an expenditure of, at the outside, not more than £15,000, the dock accommodation would be doubled, whereas to do the same thing with the ordinary graving dock would cost £40,000, or double the original cost, less steam engines and pumps.

He would conclude with a remark as to the larger amount of quay frontage which must be destroyed in the event of constructing six ordinary graving docks out of the main basin, as had been proposed. If the entrances averaged 60 feet in width, there would be a loss of no less than 480 feet of quay, which would evidently be a serious loss commercially.

Mr. **Kinipple** begged to state that the 'Stuart Wortley,' of 790 tons, had her copper seriously buckled, on the pontoon.

Mr. G. P. **Bidder**, Past-President, said, it seemed, that this discussion had arisen to a great extent from an expression in the Paper which was hardly consistent with the context. He did not regret that expression, because it had given rise to an interesting discussion. The expression in the Paper was, that the system described was capable of universal application. The more proper expression, perhaps, might have been extensive application. It was not a system, beautiful and perfect in its machinery as it was, which could be applied in every possible case. He was designing a dock for the Indus upon a different plan, and there were various conditions which ought to influence any Engineer before he recommended its adoption.

Some suspicion had been expressed, that the expenditure on this dock, as stated in the Paper, was not altogether *bonâ fide*. That misapprehension had, evidently, arisen from the fact, that whereas the cost of the lift was stated in the Paper to have been £88,000, somehow or other the capital of the Company was very nearly approaching to £200,000. Now both these statements he took to be correct. It was undoubtedly the fact, that this lift, with seven pontoons, could have been erected in the Victoria Docks for the sum stated; it was also undoubtedly the fact, that the Company had been involved in an expenditure of about £195,000. That expenditure had arisen from the circumstance, that the Company had to pay for the land: they had also to pay royalties; and there was also the profit and loss. He did not think he ought to be called upon to give the details of the figures, because, in this Institution, it had been held that Engineers should restrict themselves to the mechanical department, leaving those who had to apply the machinery to do it in the most advantageous and economical way they could. Taking, therefore, the construction of ten acres of dock for the reception of the pontoons, the cost of the land, and the erection of stores, together with profit and loss, the expenditure would have exceeded the £88,000 stated, by somewhere about £100,000.

Now, then, he thought it had been explained why there had been such a heavy profit and loss account; and yet, he was sorry to say, at this very hour, there seemed to be still some disposition to give credence to every idle rumour in respect of these works. It was suggested, that to almost any ship that entered the dock, some misadventure happened:—either she was twisted out of shape, or her copper was damaged. But he confessed he was surprised to find it stated, at this late hour, that a vessel in the dock was cambered or hogged, to the extent of 8 inches, or 9 inches; and that the vessel afterwards became depressed to a corresponding extent in the opposite direction. He had asked the name of the vessel. No name was given; but this remarkable circumstance was said to have taken place upon one of four days. Those four days had been investigated, and it was proved that during two of those days no vessel was lifted: on one day, a little vessel of 120 tons was lifted, and on the other, a ship of 870 tons was lifted: and he could state on behalf of the Dock Company, that no complaint had ever been received by them in respect of any damage which those ships had sustained in the dock, nor, in fact, any others; on the contrary, vessel after vessel that had been there before came again to the dock.

There appeared to have been an impression, that the Victoria Dock Company had established this system. They declined it; and it was done entirely by a private Company. What would have been the cost of this system if the Dock Company had adopted it? The origin of this dock was owing to the fact, that when the Victoria Docks were being made, he felt very strongly, that a graving dock added to those docks would be found to be a useful auxiliary and would tend to attract business. He accordingly set to work to design a graving dock in the ordinary way. He tried wrought iron and cast iron, with brickwork, and every other possible material he could conceive to make a durable work; and he could not get any one design to work out at less than £50,000 for a dock capable of taking in a vessel 320 feet, or 330 feet long. It was obvious that would not pay. The Dock Company would not undertake it. Then he tried all manner of contrivances for floating vessels, and he hit upon that plan of close pontoons, which accomplished the disaster mentioned in connection with the London Docks. He saw it had no stability, and he confessed himself defeated. It was then Mr. Clark took up the subject and designed this lift.

Now, if the Victoria Dock Company had established it, there would have been no occasion to have bought the 24 acres of land; there would have been no occasion to have made the dock in the manner in which it was made. All they would have had to do, would have been to establish the dock during the progress of the works. That lift cost, with the machinery, £30,000 at the most. But, it was to be borne in mind, that this was the first application of a new invention; and he did say, that the fact of its being so successful, so that there had been no failure originating from the scheme itself, from that time to this, was most remarkable. The late Mr. Robert Stephenson, who took a great interest in this work, pecuniary as well as personal, when discussing it with him, said, "Depend upon it there will be some serious disaster at starting."

In the discussion, this new experiment had been compared with docks built on established data and on the experience of years past; a new invention was compared with old and tried works. That was an element to be taken in favour of this scheme. If the London, or Victoria Dock Company had applied it they would have had the lift with all the appliances and machinery for £30,000, and £12,000 more would have given them a pontoon capable of supporting a vessel of 3,000 tons. They would have had a graving dock for £40,000 or thereabouts, and more available than a graving dock of the ordinary form. They need not have had the pontoon to have gone off the lift; but they would have had a perfect graving dock for £40,000, occupying no more space than the vessel itself lying in dock. It had been stated, that docks had been made in the beautiful stone at Birkenhead for £16,000 or £17,000 each, and that similar ones had been made at Falmouth. The cost of other kinds of docks, at Sunderland and the Tyne, had also been given. The three docks at Southampton were not made quite so cheaply, having cost, including land, £150,000. But at all events, for a sum of £40,000, the Victoria Docks might have had a perfect graving dock; for £12,000 more there might have been two; and, for a total outlay of £76,000, three; and nothing applied to the Victoria Docks could have been so useful, or economical, as the lift. But there were situations where there was a higher lift of tide, where the soil was more favourable, and where the trade was not of the enormous character of the Thames, in which, he thought, this system should not be applied. All that was contended for in the Paper, and all that he contended for, was the perfection of the invention as applied in the present instance, and that it was capable of extensive, though certainly not universal application. It had been stated that four and a half hours were occupied in the entire operation of lifting, though the lifting itself was effected in twenty-five minutes. He must be excused for saying, there was a fallacy in that statement, because all the time the blocks were being put in, the lift need not be occupied. The moment the ship was lifted, the pontoon was floated off, and another pontoon could be brought on, if necessary. The lift would raise about twelve vessels a day. The last time he was there, the lifting of a vessel was just commenced. About two hours after he could see neither pontoon nor ship. It appeared that the ship was required to be examined by the surveyors of Lloyd's after sustaining an accident, and she was lifted, lowered again, and taken away; and the pontoon was ready for another ship in two hours, and the ship gone. In the establishment of this lift, many of his friends had a pecuniary interest, as well as himself. But one thing they stipulated for, that they would have no share whatever in the patent-right of the invention, because, in the first place, the principle of the thing was objectionable, and, in the next place, being Engineers, it was not consistent with their position to recommend a thing in which they had a personal interest.

He had only one further remark to add: that he looked upon this as one of the greatest engineering feats of the last twenty years. That the system should have been brought so nearly to perfection—worked with so much safety on a first experiment—was, to his mind, something marvellous; and when it was said, it required judicious management to insure the safety of vessels on the lift, he need only state, that upwards of a thousand ships had already been lifted with perfect safety, which showed, he thought, that the amount of judicious management required was not beyond what could be practically relied on.

Mr. GILES explained, that when he stated it took four and a half hours to get a vessel on the pontoon, he did not intend to imply that it required that time to lift the vessel. He should be glad to hear what was the greatest number of vessels lifted in one day.

Mr. J. Scott Russell said, he thought it was the general opinion that the Author's invention was a very admirable one; that all the mechanical arrangements were excellent; that the idea was remarkably original, and that it had been carried out in a most successful manner: but he thought the Author did it somewhat of injustice when he brought it before them, if he considered it was better than any other description of graving dock, or floating dock; and that it was better than those inclined slips which were also used for repairing ships. They were left to draw the inference that all other plans were either very dear or very bad, and that the Author's plan was the best for repairing ships. He was of opinion that graving docks were in certain circumstances better and more economical than the Hydraulic Lift Graving Dock, that floating docks, not of this description, were in some circumstances more economical, and more applicable, and that what are called inclined slips were superior to the arrangement adopted by the Author. He should be sorry to say that the hydraulic lift was not the best thing that could have been invented under the special circumstances of the case.

He would enumerate circumstances in which it appeared to him that the plan under discussion did not possess so great merit as it might be inferred was attributed to it.

He submitted, that where there was a good rise and fall of tide, a shore with deep water close inshore, a soil able to carry the weight of a ship, and not hard to work, good hydraulic lime, and building material cheap and ready at hand, an ordinary graving dock was cheaper in first cost, and cheaper in working, than this hydraulic lift. Engineers should consider well all such circumstances before they abandoned the graving dock. In discussing graving docks as graving docks, they should not compare a costly granite graving dock, with an economical arrangement, such as they would make for a private builder. In a tideway, a dock could be easily made. He recollected having a dock made for the repair of small ships, designed by the owners, to be done at small expense. In the yard, alongside the Thames, a space was excavated large enough for the size of ship to be repaired. The bottom of that dock was gravel: it was not even lined with timber, and a simple pontoon floated in kept out the tide, and that was a graving dock of the simplest character, but of the most perfect possible description. Then they had the timber graving dock common amongst shipbuilders, and, finally, the dock lined with brick and granite.

Where they had a gently sloping bank of good solid material shelving down continuously into deep water at an angle between 1 in 24, or 1 in 50, or 1 in 60, the patent slip, as it was called, appeared to him better and cheaper than the hydraulic pontoon dock. In such a place they had nothing to do but lay down the ways and haul up the ship. If they chose simply to haul a ship up a wooden way, well greased, one twenty-fourth part of the weight of the ship would overcome the friction of the ways. If they put the vessel upon rails, he need not say that one-fiftieth of the weight of the ship would overcome the resistance of the ways; and, if the slope was up to 1 in 12, which was not the usual form of slip, a system of slips and carriages had been used, by which the ship was raised broadside out of the water. All these were arrangements of which they had had ample experience, and when he told them that each of these plans of slips might be constructed to bring up a vessel of 3,000 tons at an expense, in the way of capital, of £2 per ton of the ship, it would be seen that that also was a very economical arrangement. With regard to a graving dock, it would cost a great deal more: it might cost £5 per ton of the ship which it took in.

The last arrangement of which they had the choice, independently of the Author, was the ordinary floating dock, and the question was raised, in what circumstances was the ordinary floating dock better than that under discussion? There was one point in common with the Hydraulic Lift Graving Dock and the ordinary floating dock, and it consisted in the comparatively small depth and great breadth of the pontoon; in the Author's, he believed it was 6 feet deep by 60 feet wide and 300 feet long. The difference between this and some other floating docks consisted not in this apparatus, by which the ship was carried, but in the machinery which raised and lowered her. The Author sank a series of cylinders, each containing a hydraulic ram, and the presses were connected with a platform, and, by a steam engine and hydraulic apparatus, the platform was gradually lowered down into the water. After the platform was sunk under the water no more force was necessary to lower and raise it, and therefore the machinery was simple, and had the least possible friction; but the moment he placed a vessel on the top of the pontoons, the cost and labour of raising up the ship out of the water was incurred, and for this purpose it was supported in various ingenious ways, which had been explained. In the ordinary floating dock, instead of the hydraulic apparatus being fastened to the ground, it was put on the top of the pontoon in the shape of a long parallel caisson of the same nature as that on which the ship floated. Then, by admitting water into the longitudinal caissons, the pontoon was sunk below the vessel; the water was again pumped out of the longitudinal caissons, and the vessel was gradually raised. All that was necessary beyond this was to pump as much water out of the pontoon as was equal to the weight of the ship raised above the water. In a plan previously explained, instead of these pontoons being filled with water, the platform had been lowered by screws, and a variety of inventions had been used for lowering the platform and for raising it.

As regarded the Hydraulic Lift Graving Dock, and the ordinary floating dock, the circumstances of position were, in his opinion, of more importance than the mechanical arrangement. For example, where shallow water was abundant, where an extensive area of sheltered water existed, where there were no tides, and where foundations were met with at no great depth under the water, the Author's invention was most applicable. But where a rocky coral shore existed, as at Bermuda, or a bad foundation and great depth of water, then the ordinary floating dock was the best arrangement, and for such a position the Author's was not a good arrangement. The former condition, favourable to the Author's arrangement, existed in the Victoria Docks. He urged that by far the most valuable part of the hydraulic lift, on which he placed great weight, even more than the Author himself did, consisted in the multitude of the ships which could be floated in shallow water at comparatively small expense. The Author took, as it were, a single dock with its apparatus, and by this single dock and apparatus he had incurred the greater part of the expense and outlay; for by a simple method of detaching from this fixed apparatus the floating pontoon, he was able to multiply its usefulness, and to employ the same area for a great many ships, all of which had been lifted by the same apparatus. Therefore the following were the special circumstances under which the invention might be exclusively and profitably used—where there was protected and deep water to form the dock, where there was not much rise and fall of tide, and where it was required occasionally to put into repair, at the same time, a large number of vessels in comparatively shallow water. There it would be most useful, and better than any other mode he had described, or with which he was acquainted.

Mr. Edwin Clark said, before he replied to the various questions, he begged to thank the Institution for the time which had been devoted to the discussion, and for the kind manner in which his Paper had been treated by all who had taken part in it. He was glad to find, that although he had pointed out no less than nine features, in which this kind of dock possessed advantages over others, yet the principal point which had excited discussion had been the question of cost.

With respect to the cost of these docks, some confusion had arisen, from the manner in which the subject had been treated. Throughout the discussion a dock had been spoken of as costing so much money, without regarding the dimensions of the dock. It would be as definite to speak of a ship costing a certain sum, without regard to her size, &c. It had been assumed that the dock he had made at the Victoria Docks was of a standard size, and that its cost was to be taken as the price of such docks in general, and the whole discussion had been based on this assumption. It was stated that several docks at Birkenhead had been constructed at extremely low prices, in which respect those docks appeared to contrast very favourably with the lift. In other examples, such as those at Southampton and Bow Creek, the advantage of the lift, with respect to economy, was frankly admitted. Now Birkenhead was a locality purely exceptional. The site possessed all those natural advantages which had been described as peculiarly favourable for an ordinary dock. The sandstone was easy to cut and work; it was free from fissures, and the stone itself, when cut out, was a valuable building material; and in the excavation of a dock in such a situation it was so valuable, that he could scarcely understand why the dock should cost so much as was stated, because the quarrying ought to be sufficient to pay for it. Such a dock was not a fair subject for comparison with this lift. It had indeed been stated, that this lift had been erected in the Victoria Docks under circumstances offering some peculiar facilities. He was anxious to disabuse the minds of the Members from any idea of the kind. He had had the pleasure of designing eighteen or twenty docks in various situations, and he might say, of all the number, there was no situation which presented the difficulties which he encountered at the Victoria Docks. He could hardly conceive a situation of greater difficulty. In the first place, it adjoined a deep dock full of shipping, where it was of the utmost importance that the water should be kept from running away. Nevertheless, he had to make an entrance into that dock, and for that purpose, to construct a costly cofferdam. Then an excavation was required for the lift pit, and that, in a bad soil expensive to work. The whole of the land was, besides, of a costly character, and the surrounding competition of more than eighty other docks had to be contended with. Amongst all the other docks he had designed, he had not met with a situation where the facilities were not much greater than at the Victoria Docks. Hydraulic Lift Docks, as a rule, ought to require little or no excavation. The principal feature was, that wherever he could fix a cast-iron column, there he could make his dock. In many situations, as at Vancouver, Barcelona, and Marseilles, there was no excavation. Having obtained a spot with sufficient depth of water, the sinking of the columns was the only work to be done. He wished, therefore, to correct the impression, as to there being any advantages in the site at the Victoria Docks, and if this dock could compete with others in the Thames, he was quite sure it could do so elsewhere.

Two or three questions had been asked, to which he wished now to reply. First, as to how ships could be lengthened on the pontoons in this dock; and how other works of that class could be carried out. Also what was the cost of the manipulation of such docks, and further, whether the vessels were not inaccessible on account of their being on a level with the floor of the workshop? With regard to the last point, he apprehended the object of lifting a vessel out of the water was to get access, not to the inside but to the outside, and for that purpose, he could not conceive anything better than bringing the vessel on the level of the floor of the workshop, instead of having to go down stone steps to it. On the other hand, when ships were built, it was done on a level with the building yard; and as to the lifting of iron plates and other weights, his experience showed, that no great amount of that kind of work was required in dock, the work to be done being generally painting, coppering, or partial repairs to the hull or keel, &c. As to putting in boilers, no one would think of doing that while a vessel was either in a stone dry dock, or in this dock, as a crane could scarcely reach over 60 feet of dock; but it was effected with shears alongside the wharf in a deep-water dock.

On the second point, as to the cost of manipulation, he had stated, that the average had been £3 per ton upon the 1,030 ships that had been lifted, as against £13 at the docks at Southampton with 700 ships, although doubtless, a larger class of vessels was docked at Southampton than in this dock. He had no means of knowing what the cost was at Birkenhead docks. With respect to how far it was possible to effect, on a pontoon, such an operation as that of lengthening a ship, the way in which it was done was this: The shallow dock had a level bottom, and, by running the water out of the shallow dock, the pontoon was brought down and grounded upon the floor of the dock. Then there was a platform of timber 350 feet long, or more, and 60 feet wide, perfectly true, to enable a shipbuilder to judge of his lines; and no better situation could be conceived, either for cutting a ship in two and lengthening her in the middle, or for building a ship outright; and he believed the system would come into general use for shipbuilding. The accident that had just occurred to the 'Northumberland' could not have happened if she had been lowered on a pontoon instead of by the ordinary way of launching; and the American Government attached so much importance to that plan, that they adopted it for launching their vessels; and he was sure, the interest upon the cost of the pontoon would be far less than the expenditure incurred in the preparation of the present launching ways, with so much timber cut to waste, not to speak of the risk that must attend the launching of vessels of such great weight. Then, again, by the use of pontoons, the number of places where ships could be built, was multiplied. Any of the Surrey timber ponds, in which the pontoons would float, might be used for the building of the largest ships, and in the launching, a small lift only would be required. To launch the 'Northumberland' a 1000-ton lift would be sufficient.

With respect to the general request that he would point out the difference between the system of raising with hydraulic power, and that of simply emptying the pontoon of water, he would occupy a few minutes in explaining clearly, he hoped, the difference between the two. With any floating body, such as an ordinary pontoon, the stability depended upon the fact, that some portion was out of the water, and any change of position produced extra immersion or emersion in that part; but when a body was entirely submerged, no change of position could produce any difference in that respect, and a submerged body had consequently no stability: walking from one side to the other would tilt a submerged pontoon, unless it was forcibly maintained in a horizontal position. One of the plans suggested was the parallel motion, which had been tried at the London Docks, the rods being attached to the pontoon and to the bottom of the dock by cast-iron piles driven into the ground, the object of which was to maintain the horizontality of the ship. This plan failed; the strain on those rods, which varied as the tangent of the angle made with the vertical, becoming very great as the water closed, and ultimately infinite. Hence the cause of the accident: the rods broke and went through the bottom of the vessel; the water could not be pumped out; and, in subsequently trying to force in air, the deck was blown out. The other system, usually adopted, for rendering the position stable, was to make the sides hollow and of sufficient height to remain partly out of water. The sides were towers, 40 feet high. In these towers, were placed hollow boxes, which by means of screws, or chains, or some other contrivance, could be raised and lowered: the consequence was, as these boxes were always on the surface of the water, this pontoon could be lowered and the stability maintained, so long as both chains were lengthened to the same amount and at the same time. In that way the stability was maintained in the American Canal Dock. Sometimes this was done in the form of a large chamber, which had to be filled with water. In all these cases, a great difference would be observed between this pontoon and his own. The pontoon he used was perfectly open: it was never subjected to a greater strain than a pressure equal to the draught of water which it drew; and, drawing 6 feet of water, the greatest pressure was a column of water 6 feet in depth. The pontoon was consequently light and inexpensive, but in lifting with a submerged pontoon it must be sunk 26 feet or 30 feet deep in the water, and therefore, being subjected to a proportionate pressure, the quantity of iron required to strengthen it and to form the deck made it a more costly thing than the whole of the presses and pumps put together. Then, in addition, the manipulation of a large number of these boxes required a large staff of assistants. If a vessel were 300 feet long, with eighteen boxes, about forty men would be required to work them uniformly. It was a difficult engineering operation, requiring much skill and management, and after all, it was only one dock: but with his plan twenty pontoons might be worked by a single lift, with six men.

He did not say, that his dock was of universal application: he agreed, there were many circumstances, in which docks of another description were better. There were many cases in which a slip would be better than his dock, or any other dock, and there were other cases, where a stone dock would be better than this lift; but still it was capable of very general application. The principal difficulty was, in respect of the cost of the iron columns, where the water was too deep; and to meet such cases, Mr. Walker had suggested the plan of putting the presses themselves in pontoons. But where the water was of proper depth, there were few cases in which a dock of this kind would not be far more economical than an ordinary stone dock.

With respect to the stiffness of pontoons, he wished to state, that in advocating a partially elastic pontoon, he was giving the result of practice. He had stated that, from the experience of more than a thousand ships, an elastic pontoon was best, and produced no strain; but if a rigid pontoon was wished for there was nothing to prevent the sides being made 40 feet high; and any amount of rigidity might be obtained. If a captain wanted to beach his vessel, he always preferred to do so on a soft place; but that was a matter of judgment.

A great deal had been said with regard to the commercial failure of this undertaking. He did not think he was called upon to enter into that subject, nor did he think it concerned him. An Engineer might construct a superior quartz crushing machine; but it might be sent to a bad gold mine. If proper use was not made of the hydraulic lift machine he was sorry for it.

To return to the subject of cost, he wished to put the matter in a simple form. The cost of lift, engine, pumps and all complete and fixed, would not exceed £10 per ton upon the weight to be raised—his cost £7 per ton. The cost of the pontoon might be taken at £5 per ton upon the weight to be floated. The cost, therefore, of a lift, for vessels of 1,000 tons, would be £10,000, and the cost of six pontoons of from 500 tons burthen to 1,000 tons burthen, would be £22,500. Thus six docks were respectively completed for £32,500, allowing a good margin of profit to the manufacturers. That was in the case of a lift not requiring more than ordinary excavation. If a great amount of excavation in difficult ground was required, as in the Victoria Docks, of course it increased the cost. If it were done at a place like Birkenhead, where the value of the stone was more than the cost of excavation, he imagined there must be great economy of cost.

Mr. Abernethy remarked that the Author had omitted comparison with the two docks at Falmouth, which were lined with granite throughout, and only cost £29,000.

Mr. Clark said, that in his illustration, there were six docks adaptable to almost any situation, and capable of indefinite extension, by adding to the number of pontoons. The machinery was simple and durable in all its parts. In comparison with ordinary floating docks, the whole of the work was perfectly accessible, especially with regard to the painting of the iron work, as there were no closed chambers, and the pontoon was raised out of the water in every operation. The rapidity with which this description of dock could be constructed was another important feature. The dock at Carthagena, of which the model was exhibited, was stated to have been commenced in the year 1861, and now in 1866, Mr. Rennie had been good enough to promise a descriptive Paper when that dock was completed. It did not take more than a year at farthest to put up the lift, and a stone dock certainly could not be built anywhere in that time. He did not know what the cost of the dock at Carthagena would be, but he was told it would be about £200,000.

March 6 and 13, 1866.

JOHN FOWLER, President,
in the Chair.

The discussion upon the Paper, No. 1,155, on "The Hydraulic Lift Graving Dock," occupied both evenings, to the exclusion of any other subject.

The following Candidates were balloted for and duly elected on March 6th:—Hugh Carlile, Edward Read Nelson Druce, Richard Hassard, and Robert Morgan, as Members; Henry Anderson, Charles Ormsby Burge, Edward Charles Cracknell, William Dempsey, Hamilton Edward Harwood, David Marr Henderson, Graham Hewett Hills, George Knowles, John Lean, James Campbell Ledger, George Leeman, M.P., Samuel Henry Louttit, Emile Martin, Edward Adolphus Fenwick Mayer, Henry Oakley, John Robinson, Thomas Harrison Seacome, George Thornton, George Careless Trewby, William Vawdrey, and Henry William Wickes, as Associates.

March 20, 1866.

JOHN FOWLER, President,
in the Chair.

No. 1,152.—"On the Maintenance and Renewal of Permanent Way."[1] By R. PRICE WILLIAMS, M. Inst. C.E.

THE contrast afforded by the perfectly smooth and almost imperceptible motion which now obtains, even at express speeds, on the principal main lines of railway, is particularly striking to those who can remember the early days of railway locomotion, with its stone blocks, unfished rails, and noisy jolting motion, at what would now be considered a most moderate speed. At the same time it must be reluctantly confessed, that the condition of the permanent way, so far as regards its durability, has in no way kept pace with the demands made upon it, by the present high speeds and heavy and increasing traffic; and in this respect it compares most unfavourably with the marked progress observable in other branches of railway engineering. Taking the improved structure of the modern locomotive as an illustration, it will be found that, whilst its weight and power have, in a period of thirty years, more than quadrupled, the increased efficiency resulting from more perfect workmanship and a better description of material is such, that the per-centage on the gross traffic receipts of locomotive expenses on the Great Northern Railway has even slightly decreased during the last fourteen years, while, on the other hand, the per-centage on the gross traffic receipts of maintenance of way has increased more than 200 per cent. in a similar period.[2]

It would seem as if the first introducer of this beautiful machine had intentionally left the investigation of the true principles which should regulate the construction of the permanent way, as a problem to be solved only by long and varied practical experience. Certain it is that the Rocket, with its light weight of 4½ tons, and moderate

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[1] The discussion upon this Paper extended over portions of five evenings, but an abstract of the whole is given consecutively.

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Vide Reports—June,	1851,	locomotive expenses,	17·03	per centage on gross traffic receipts.
Appendix, p. 373 ,,	1865,	,,	16·94	,,
,,	1851,	maintenance of way and works.	3·23	,,
,,	1865,	,,	9·99	,,

speed of twenty miles an hour, at once proved too much for the first permanent way of the Liverpool and Manchester Railway; since its light, fish-bellied rails were quickly replaced by others of a heavier character, uniform in depth, of the section so well known as the double T-headed rail.

It is not the purpose of this Paper to give a history of the numerous inventions which have from time to time been brought forward for improving the permanent way. It is enough to say that, so far, none of them have realised the desired object; for, with the exception of the now generally-adopted method of fishing the ends of the rails, the substitution of wooden sleepers in the place of stone blocks, and the employment of a heavier class of material, the original system, introduced thirty years since, still remains in use. Accumulated experience now seems to show, that it is not so much by any ingenious or more scientific disposition of the materials employed, nor by the substitution of iron alone in the place of the more elastic and perishable substructure, that a corresponding improvement must be looked for in the condition of the permanent way; but rather to the judicious and liberal use of a better and more durable class of materials. For the failure of the iron sleeper road no higher authority can be quoted than Mr. W. H. Barlow, himself the inventor of the well-known saddle-back rail, which, from its originality, and the combination of scientific principles displayed in its design, at once recommended it to extensive adoption. Mr. Barlow, during a discussion in this Institution, candidly admitted its failure, and further stated his deliberate opinion that, "on roads which had to sustain the heavy loads and great speeds of the main lines of this country the employment of timber was unavoidable."[1]

Without advancing any speculative opinions of his own, as to what is theoretically the best form of permanent way, the Author thinks it will be at once conceded, that no system can lay claim to any such character, which does not provide for a due amount of elasticity in the substructure, in order, as far as possible, to neutralise, or absorb, the momentum of the passing loads.

With a view of showing that the durability of the permanent way, and more especially what has been termed the 'life of a rail,' have been considerably over-estimated, and further with the object of supplying more reliable means for comparing the cost of maintenance and renewals on different railways, the Author has been engaged for some years in preparing, from the published reports and other reliable sources, with the assistance and full concurrence of the different railway officials, tables and diagrams relating to the following lines of railway, arranged according to their mileage in the order following:—

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xx., p. 282.

1. The London and North Western.
2. The North Eastern.
3. The Midland.
4. The London and South Western.
5. The Great Northern.
6. The Lancashire and Yorkshire.
7. The South Eastern.
8. The London, Brighton, and South Coast.
9. The Manchester, Sheffield, and Lincolnshire.

These tables and diagrams show, for a period of nineteen years,

1st. The detailed charges usually comprehended under the head of maintenance and renewal of permanent way and works.

2nd. The number of miles maintained.

3rd. The train mileage.

4th. The gross tonnage, together with other information bearing upon the subject.

The information to be gathered from the reports prior to the year 1847 being of a very scanty and unreliable nature, the Author has not thought it advisable to carry his inquiries beyond that period.

The objection has been urged, in previous discussions on this subject, that the comparative cost of maintenance of permanent way is a problem incapable of satisfactory solution, on account of the great variation in the mode of keeping the accounts on different railways.[1]

To meet this objection great care has been taken to omit from the calculations, in all cases, items such as gatekeepers, police, &c., ordinarily considered as traffic charges, but occasionally found included under the head of permanent way. Similarly, repairs to harbours, docks, telegraphs, canals, and other works unconnected with the permanent way, have, wherever they have appeared, been excluded. By this means, and by adopting the following general classification of the different charges usually comprehended under the head of "maintenance and renewal of way and works," it is hoped that sufficiently detailed information is furnished, in each instance, to enable a general comparison to be made, and at the same time to afford an approximate idea of the expenditure which has occurred, during a considerable period, on some of the principal lines in this country:—

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ix., p. 387; vol. xi., pp. 282, 292, 297.

First, Maintenance of Way, including wages, materials, ballast, &c., is indicated on the diagrams (Plates 14 to 19) by the portion coloured *blue*.

Second, Staff and other charges, including superintendence, assistants, inspectors, office, and other charges, are indicated by the *white* portion.

Third, Works of Line, including repairs of gates, fences, roads (not at stations), slips, culverts, &c., and repairs (and occasionally renewals) of viaducts, bridges, and tunnels, are indicated by the portion coloured *green*.

Fourth, Stations and Station Works, including repairs to sidings, houses and buildings, stations, approach roads and yards, points and crossings, and gas and water service, &c., shown by the portion coloured *yellow*.

Fifth, Renewals of Way, including all materials and labour (occasionally materials only), shown by the portion coloured *red*.

In the Midland and the London and South Western accounts, maintenance of way, and of works of line, are included under one head. As, however, these items immediately follow each other in the order of arrangement of the tables, it is only necessary to combine them for the purpose of comparison with the other tables and diagrams. The lowest full hard line on diagrams 1 to 9 (Plates 14 to 19), shows the cost per mile per annum during each half-year of ordinary maintenance of way, including wages and materials. In some cases, it will be observed that wages and materials are shown separately, in others combined. The next line above shows the staff and other charges; the third, coloured green, the works of the line; the fourth, station works. The topmost line shows the annual cost per mile for renewals during similar periods, and at the same time shows the aggregate cost per mile per annum of the whole of the charges included under the head of "maintenance and renewals of way and works."

The stars (* * * *) on the diagrams indicate the number of miles maintained, to a scale of $\frac{5}{8}$ths of an inch to 100 miles. The dotted lines (—.—.—.) the train mileage, to a scale of $\frac{5}{8}$ths of an inch to a million miles. The vertically scored line with the black dots shows the gross half-yearly tonnage. The diagonally scored line shows the cost per mile per annum of renewals, according to the amount set aside for that purpose in the suspense accounts.

Taking the London and North Western Railway (diagram, No. 1, Plate 14), by way of illustration, it will be noticed, that in 1847 the number of miles maintained amounted, at that early period, to 378½ miles; that the cost of the first item, "maintenance of way," had reached £270 per mile per annum; and that that of the second, "staff and other charges," preserves throughout, down to the present time, a very regular and even outline. The third item, however, "works of line," shows considerable variation, due, probably, in a great measure, to the heavy and exceptional expenditure at times in replacing the timber viaducts, repairing slips, &c. The next item, "stations and station works," also exhibits the same variable character. It is, however, in the last item, "renewals of way," that the principal disturbance of outline is most noticeable. Already, in 1847, the permanent way of this line —which may justly be termed the parent of the English railway system, since it had its origin in the Liverpool and Manchester Railway—showed evident signs of rapid deterioration, as the cost of renewals, at this early period, amounted to £38 per mile per annum. It rapidly advanced during the following five years, until in 1851, it reached £101 per mile, and the total expenditure in renewals attained £132,502. Taking the cost of renewing a mile of single way (allowing credit for old materials, and exclusive of ballast) at the liberal average of £1,400 per mile, this would represent something like 94½ miles of single line, or about one-seventh of the whole double mileage maintained in 1847, entirely renewed during that period. In the next five years, from 1852 to 1856 inclusive, the cost of renewals advanced to just £200 per mile per annum, and the expenditure during this second period amounted to £630,001; equivalent to about 450 miles of additional single line—a length which, with the 94½ miles renewed in the preceding five years, corresponds to two-thirds of the whole double mileage (378½ miles) maintained in 1847 renewed in ten years. In the following five years, from 1857 to 1861, the cost of renewals averages nearly £200 per mile per annum, while the expenditure in this third period has amounted to £599,139, or to about 428 more miles of single line; the aggregate expenditure during the fifteen years having reached the large total of £1,341,662. In the remaining three and a half years, from December, 1862, to June, 1865, the cost of renewals has averaged £151 per mile per annum; while an additional outlay during that period, of £545,216, has been incurred, representing about 389 more miles of single way, forming altogether, in the nineteen years, a grand total of £1,906,858, expended on renewal of way alone, and representing something like 1,363 miles of single line, or almost half the whole mileage maintained in the year 1865.

It will further be observed that the average annual expenditure of this Company for renewals since 1847 has amounted to £103,074. This represents something like 73 miles of single way of the main line broken up and entirely replaced annually during this period; chiefly in situations where the traffic was heaviest, and where consequently (owing to the short intervals between the trains), the facilities for doing the work are the least, and the danger of accident the greatest.

In a report to the Directors of this railway some years since, the result of an elaborate inquiry into the question of the durability of the permanent way, by the officials of that line, the average life of a rail was stated to be about twenty years. This estimate, however correct when based on the circumstances and conditions of the traffic at that time, certainly does not seem to be borne out by the facts shown in this Paper. The average cost per mile per annum during the period of about nineteen years referred to is £145. Dividing £2,800, the average original cost of a mile of double line of permanent way, by this amount, the average life of a rail for the whole of the mileage maintained is found to be nineteen years. A large portion, however, of this mileage was not in existence nineteen years since—a considerable mileage, indeed, having been opened within the last few years, while another large part (about ten per cent.) is represented by single branch lines, many of them of comparatively light traffic. It may, therefore, be safely assumed, without pretending to be in possession of any specific or detailed information on the subject, except such as is afforded by the reports, that this vast expenditure has occurred on a very limited portion of the mileage. Probably, (as will presently be shown to be the case on a neighbouring railway,) it represents the renewals and re-renewals of those portions of the main line where the traffic is heaviest.

The average cost of renewals, per mile per annum, during a period of years, on the other railways is as follows:—

			Per Mile per Annum.
1.	London and North Western Railway	(average of 18½ years)	£145
2.	North Eastern Railway	(,, 14 ,,)	£83
3.	Midland Railway	(,, 17½ ,,)	£84
4.	London and South Western Railway	(,, 11 ,,)	£72
5.	Great Northern Railway	(,, 9½ ,,)	£110
6.	Lancashire and Yorkshire Railway	(,, 16½ ,,)	£156
7.	South Eastern Railway	(,, 15½ ,,)	£102
8.	London, Brighton, and South Coast Railway	(,, 12½ ,,)	£94
9.	Manchester, Sheffield, and Lincolnshire Railway	(,, 9 ,,)	£49

The limits of this Paper will not permit a similarly detailed reference to be made to the other tables and diagrams. It is hoped however, that, being arranged on the same plan and to the same scale, they will, with the illustration just given, sufficiently explain themselves, and with the tabular statement showing the average cost of renewals, afford the information necessary for the purposes of general comparison.

Whilst the results afforded by the diagrams and tables 1 to 9 are sufficient, it is imagined, to show in a general way, that the rate at which the renewals of permanent way have been going on is more rapid than is usually thought, it must be admitted that they are too general in their character to afford a reliable estimate to be formed of the life of a rail. The Author, however, having some years since had charge of a district on the Great Northern Railway, has been enabled, through the kind assistance and co-operation of its chief Engineer, Mr. Johnson (M. Inst. C.E.), to supplement the tables and diagram, No. 5 (Plate 17), showing the cost of maintenance and renewals on that railway, by longitudinal sections of the two principal divisions of the main line (Plate 20), showing the particular parts of the line at which the renewals have occurred, the periods of renewal, and the nature of the different geological formations traversed by the line.

The Author is greatly indebted to Mr. Johnson and the other chief officers of the Great Northern Railway, for the unreserved manner in which they have afforded him information relating to the past and present condition of the permanent way of that railway.

It may be sufficient to mention, that the Great Northern Railway was opened throughout in the year 1853, the East Lincolnshire and Loop Line, together with portions of the main line between Retford, Doncaster, and Askerne Junction, having been opened for traffic in the four preceding years. This Paper, however, has chiefly to deal with the two principal divisions of the main line—the South, extending from King's Cross to Peterborough (75½ miles), and the North, from Peterborough to Askerne Junction (84¾ miles), Plate 20. Here it is that the destructive effects upon the permanent way of a large and concentrated traffic—more especially of a heavy and rapid coal traffic—are most significantly evident. The original rails laid down in 1853 were of a double-headed, reversible section, 72 lbs. to the yard, in 18 feet lengths, with joint chairs weighing 40 lbs. each, and intermediate chairs, 21 lbs. each, secured with two wooden trenails to triangular sleepers, each 13 inches by 6½ inches in section. The bottom ballast consisted of either burnt ballast, broken stone, chalk, or gravel, according to the geological condition of the district occupied. The top ballast was formed of gravel, and at the London end with burnt ballast. The latter, however, both from its destructive effects upon the sleepers, and its tendency, by retaining the water, to interfere with the efficient drainage of the line, was soon found to be unsuitable, and had to be replaced, in 1854–55–56, by good clean gravel. About the same time the joint chairs were to a considerable extent replaced by Adams's joint bracket chairs. These not being found to answer, were subsequently replaced throughout the whole of the main line with the present suspended fish joint. A single mile of this permanent way was estimated at the time to cost £1,450, credit being allowed for old materials, but exclusive of ballast.

The rails and chairs latterly used in renewing the road are of a heavier character, and the sleepers are of a rectangular scantling 10 inches by 5 inches, more befitting the increased weight and amount of the traffic; the rails are 82 lbs. to the yard, and 21 feet in length; the chairs weigh 35 lbs. each, have a broader seat, and are furnished with a wooden cushion for the rail to rest upon. These chairs are fixed to sleepers by means of two spikes and a trenail. The sleepers are placed 2 feet 8½ inches apart, centre to centre, except at the joints, where they are reduced to 2 feet, which is as near an approximation to a close planked road as the spaces required for packing will almost admit of. The cost of renewing a single mile of this road, as furnished to the Author by Mr. Johnson, is as follows:—

A MILE OF SINGLE LINE.

	£.	*s.*	*d.*			
Rails, 503 – 21 feet = 3,520 yards, at 82 lbs. = 129 tons, at £8 14*s.*	1,122	6	0			
Chairs, 35 lbs. each = 63 tons, at £4	252	0	0			
Fish-plates, 503 pairs, at 25 lbs. = 5 tons 12 cwt. 1 qr. 3 lbs., at £8 14*s.*	48	16	9			
Bolts, 503 + 4 + 1½ lbs. = 1 ton 6 cwt. 3 qrs. 22 lbs., at £11 5*s.*	15	3	2			
6-inch keys, 4,024, at £5 2*s.* 6*d.* per 1,000	20	12	5			
Trenails, 4,024, at £3 17*s.* per 1,000	15	9	10			
Spikes, 8,048, at 11 lbs. = 3 tons 11 cwt. 12 lbs., at £9	32	6	8			
Sleepers, 2,012, at 3*s.* 6*d.* each	352	2	0			
Cushions, 4,024, at £2 per 1,000	8	0	11			
Labour only, 1,760 yards, at 10*d.*	73	6	8			
Gross cost				£1,940	4	5
CREDITS.						
Old rails, 3,520 yards, at 68 lbs. = 80 tons, worn out, at £4	320	0	0			
27 tons serviceable, at £5 10*s.*	148	10	0			
Ditto chairs, 3,520, at 21 lbs. each = 33 tons, at £2 5*s.*	74	5	0			
Ditto fish-plates, 503 pairs, at 21 lbs. per pair = 4 tons 1 qr. 7 lbs., at £5 10*s.*	25	18	8			
				568	13	8
Nett cost				£1,371	10	9

January, 1865.

By reference to Diagram No. 5 (Plate 17), it will be seen, that for some time previous to the appearance of renewals in 1856, the large cost of maintenance clearly indicated that the rapid increase in the traffic—particularly the heavy through coal traffic—was beginning seriously to tell upon the condition of the road. To this cause, and to the cost of removing the burnt ballast, and to fishing the road, must be ascribed the high rate of maintenance at this period. The cost of renewal during the first half of the year 1856 was £35 per mile per annum; and about 2¼ miles of the up main line was relaid, on the descending gradients between Hitchin and London.

In December, 1860—seven years subsequent to the opening throughout of the line—the cost of renewals had reached £238 per mile per annum; and £158,800 had been expended in renewing about 134¼ miles of single line, including nearly the whole of the up and down lines between Hitchin and London, and the re-renewing of a portion of the mileage relaid so recently as 1856.

In the succeeding five years—1861 to 1865—181 additional miles of single line had been relaid, making altogether a total of 315 miles entirely renewed on the main line between King's Cross and Askerne Junction, at an expenditure of £423,280. Distributing this amount over the twelve years, the average annual charge is £35,273, equivalent to above 1 per cent. on the ordinary stock of the Company. In other words, the renewals which have been made on the 160¼ miles during the above-mentioned period have amounted to an average cost of £200 per mile per annum.

In order to account for the greater frequency of renewals on the up line, it should be explained, that the up traffic, including, as it does, all the heavy coal trains, exceeds that on the down line nearly in the ratio of 2 to 1; and, as might naturally be expected, the cost of maintenance and renewals will be found to be much in the same relative proportions.[1] It will further be observed, that the portions of the road which have most frequently undergone renewals are those on the falling gradients of the up line between Potter's Bar and London; clearly showing that it is to the great momentum acquired by the heavy goods and coal trains in descending those gradients that these destructive effects are chiefly due. This opinion is further confirmed by the fact, that on a similar rising gradient between the 63rd and 66th mile on the up line, the original rails still continue in place. Near the confluence of the different streams of traffic—for instance, at Hitchin and Hatfield—the frequency of the periods at which renewals have occurred becomes more strikingly apparent; most of the up line, on the descending gradients between Potter's Bar and Hornsey, has already undergone a third renewal during the short period of thirteen years, giving an average of only 3½ years as the life of a rail under these exceptional circumstances. Of the 160¼ miles of double road between King's Cross and Askerne Junction, there now remain, of the original rails laid down in 1852, about 77¼ miles of single way, chiefly, it will be observed, on that portion of the down main line between Retford and Peterborough, which, it will be remembered, was opened for traffic so late as 1853.

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[1] Up line 203 miles relaid.
Down line 112 „ „
315 „ „

Through the kindness of Mr. Grinling, the accountant of the Great Northern Railway Company, the Author has been enabled to ascertain, within very narrow limits of error, the actual weight and amount of the traffic which has passed over that portion of the line between Hatfield and London during the last 10 years. From this it would appear, that it required on the up line, near Barnet, 57,536 trains, and 11,760,926 tons, to destroy in 3 years the rails laid down in 1857; and 65,529 trains, and 13,484,661 tons, to destroy those laid down in 1860 and taken up in 1863.[1]

At the same time the Author is enabled, through the kindness of Mr. Meek, the chief Engineer of the Lancashire and Yorkshire Railway, to give the results of a most careful and elaborate investigation made by that gentleman, and extending over a period of 7¼ years, showing the comparative merits of different kinds of iron rails, supplied by some of the principal rail manufacturers of the country. A number of experimental rails of each make were laid continuously at the different stations, and these from time to time have been carefully examined, and the results noted. The number of trains and the tonnage that has sufficed to wear out these rails have also been carefully ascertained.

The results enable a comparison to be made with those just referred to; and the truth of the old saying, that 'it is the pace that kills,' is here very clearly exemplified; for the traffic on the Lancashire and Yorkshire, where the rails were laid down, although of a very heavy character, is slow, compared with that on the portion of the Great Northern line between Potter's Bar and Hornsey.

The results given by Mr. Meek show, that on the falling gradient of 1 in 130 at Ramsbottom viaduct, situated between Bury and Accrington, where the traffic is of a mixed character, 62,399 trains and a gross tonnage of 12,451,784 wore out the best sample of rails experimented upon in 7¼ years; while in the case of the Great Northern, just referred to, 65,529 trains, with a tonnage of 13,484,661, were sufficient to wear out the rails in 3 years. At Bolton, on the level, where the traffic is of a very heavy character, chiefly goods, and where all trains draw up, the same description of rails have required 203,122 trains and 38,803,128 tons to wear them out in the space of 7¼ years.[2]

That the rapid deterioration of the permanent way is in a great measure attributable to the increased weight and speed of the traffic these facts clearly show; and the concurrence of the tonnage outlines with the cost of renewals also bears a collateral proof of the truth of these deductions.

It is therefore evident that, with all the skill and care which have been displayed at various times, in strengthening and improving the permanent way, it has never at any period of its history been fully up to its work. The explanation of this fact is found in the simple reason, that the chief material, namely, the rails, is wanting in the essential element of durability. That this is so, the results of the experiments on the Lancashire and Yorkshire conclusively show; since the inherent defects, both of the best Yorkshire iron and the coarser and harder descriptions of Welsh manufacture, render them alike incapable of withstanding, for any length of time, the excessive wear and tear to which they are exposed.

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[1] *Vide* Appendix, Table 5.

[2] *Vide* Appendix, Table 7.

A reference to the mode of manufacturing iron rails will make this statement the more apparent. Plate 21 shows various methods of forming the pile, adopted at the principal iron works in South Wales. The pile, Fig. 1, is about 8 inches to 8½ inches square, in lengths according to the required dimensions of the rails. The top and bottom slabs, 2¼ inches thick, to form the table of the rail, are made out of a separate pile, 9 inches by 9 inches, of a better description of puddled bar, made from refined metal, having a highly crystalline fracture. This slab pile is twice heated before being rolled down to the dimensions of 2¼ inches. The interior of the rail pile is formed with No. 1 puddled bar, ¾ of an inch thick, arranged so as to break joint. The pile is then, with its top and bottom slab, heated to a welding heat, passed through the bolting or cogging rolls, and reduced to a section of about 6 inches square. It is subsequently reheated, and rolled into the finished rail.

Figs. 8, 9, and 10 show the form of pile used by the Ebbw Vale Company for a quantity of rails supplied to the Lancashire and Yorkshire Railway Company. The quality of the iron is very similar to that used at the Dowlais Iron Works, Figs. 1, 2, and 3. A slight difference is, however, noticeable in the construction of this pile, by the insertion of the small pieces of No. 2 hammered puddled bars at the corners, so as to lap round the top table, as shown on the diagram, and at the same time to expose a more durable surface to the action of the tyre flanges.

Figs. 4, 5, 6, and 7 represent a different mode of piling, adopted at the Plymouth Iron Works, South Wales, whereby it is considered that greater uniformity is obtained in the structure of the iron. The base of the No. 1 puddled bar is as follows:—

Clay stone ore	25 per cent.
Hematite	50 ,,
Northampton	35 ,,
Forest of Dean	35 ,,

The No. 1 puddled bars, it will be observed, are formed into a pile of twelve layers of sufficient dimensions to enable it, when rolled down into a slab of 2¼ inches thick, to be cut into three pieces to form the No. 2 pile, which is afterwards rolled into the finished rail.

Another very common form of piling is shown in Figs. 11 and 12, where the old rails form the interior part of it, the top slabs being composed of No. 3 puddled bar. Figs. 13 and 14 show an ingenious method of piling with old rails, adopted at the London and North Western Railway Works at Crewe, for the manufacture of steel-topped rails, the invention of Mr. F. W. Webb, (Assoc. Inst. C.E.)

The great objection to the form of pile in the two first instances, where crystalline iron or refined metal is used, is, that it is not of a sufficiently enduring character. The layers forming the tables of the rail are besides, when rolled down to the finished form, not more than ¼th or ⅜th of an inch thick; so that when, by the combined action of wearing and crushing, the thin top stratum is destroyed, the life of the rail is gone; the interior of the rail being of such inferior quality of material as to be incapable of any wear.

The other mode of piling, at the Plymouth Iron Works, has been adopted with the view of removing this objection, by making the pile throughout of a uniform quality of iron. It is a question, however, whether the desired object is thus obtained; whether the thin layers of ¾ of an inch of puddled bar are so thoroughly welded, and the scale so completely exuded, as not to cause the rail to laminate under the action of a heavy traffic. This has certainly been the effect observed in numerous instances which have come under the Author's notice. At the same time it is only right to mention, that cases have been observed, on the Great Western Railway, where iron rails of this particular manufacture have been exposed to the heavy main line traffic of that line for nearly nineteen years. Whether the rails were of a better material than those now manufactured is a question the Author is not prepared to answer. The fact, however, that very few makers are now disposed to give even a seven years' guarantee for iron rails, is tantamount to an admission, that where exposed to the excessive wear and tear of main line traffic their employment must no longer be looked for.

The introduction, within the last few years, of steel rails manufactured chiefly by what is known as the Bessemer process, and the highly satisfactory nature of the results obtained, encourage the belief that at length a material has been obtained which was alone wanting to give something like real permanency to that which in name only has hitherto deserved the title of permanent way.

In 1862, some steel rails were laid at the Camden Town and Crewe stations of the London and North Western Railway, where, from the excessively heavy character of the traffic, iron rails were usually worn out in the course of a few months. Two 21 feet steel rails laid on May 2nd, 1862, at the Chalk Farm Bridge, side by side with two ordinary iron rails, were, after outlasting sixteen faces of the iron rails, taken out in August 1865, and the one face only which had been exposed, during a period of more than three years, to the enormous traffic, amounting to something like 9,550,000 engines, trucks, &c., and 95,577,240 tons, although evenly worn to the extent of a little more than a quarter of an inch, still appears to be capable of enduring a good deal more work. A piece of one of these rails is, by permission of Mr. Bessemer, exhibited on this occasion. Another portion was entrusted by that gentleman to the Author, in order practically to test, by Mr. Kirkaldy's testing machine, how far its efficiency has been affected by the immense amount of traffic it has been exposed to. The results of this experiment, together with others which the Author has recently made on the comparative strength of steel, steel and iron (steel topped), and iron rails of different sections, have been carefully recorded by Mr. Kirkaldy, and are shown in Plate 22; while similar experiments on steel rails of various sections are recorded in Plate 23, and in Appendix, Table 12.

The general adoption of steel rails on main lines, where the traffic is of the heavy description referred to, will, in the opinion of the Author, not only prove cheaper in the end, but what is of infinitely more importance, will, through the less frequent breaking up of the road, materially add to the safety of the travelling public. It will also, in a corresponding degree, lighten the great weight of anxiety and responsibility which attaches to the resident Engineer, who, morally at least, is held accountable for all the accidents that occur through defects in the permanent way under his charge.

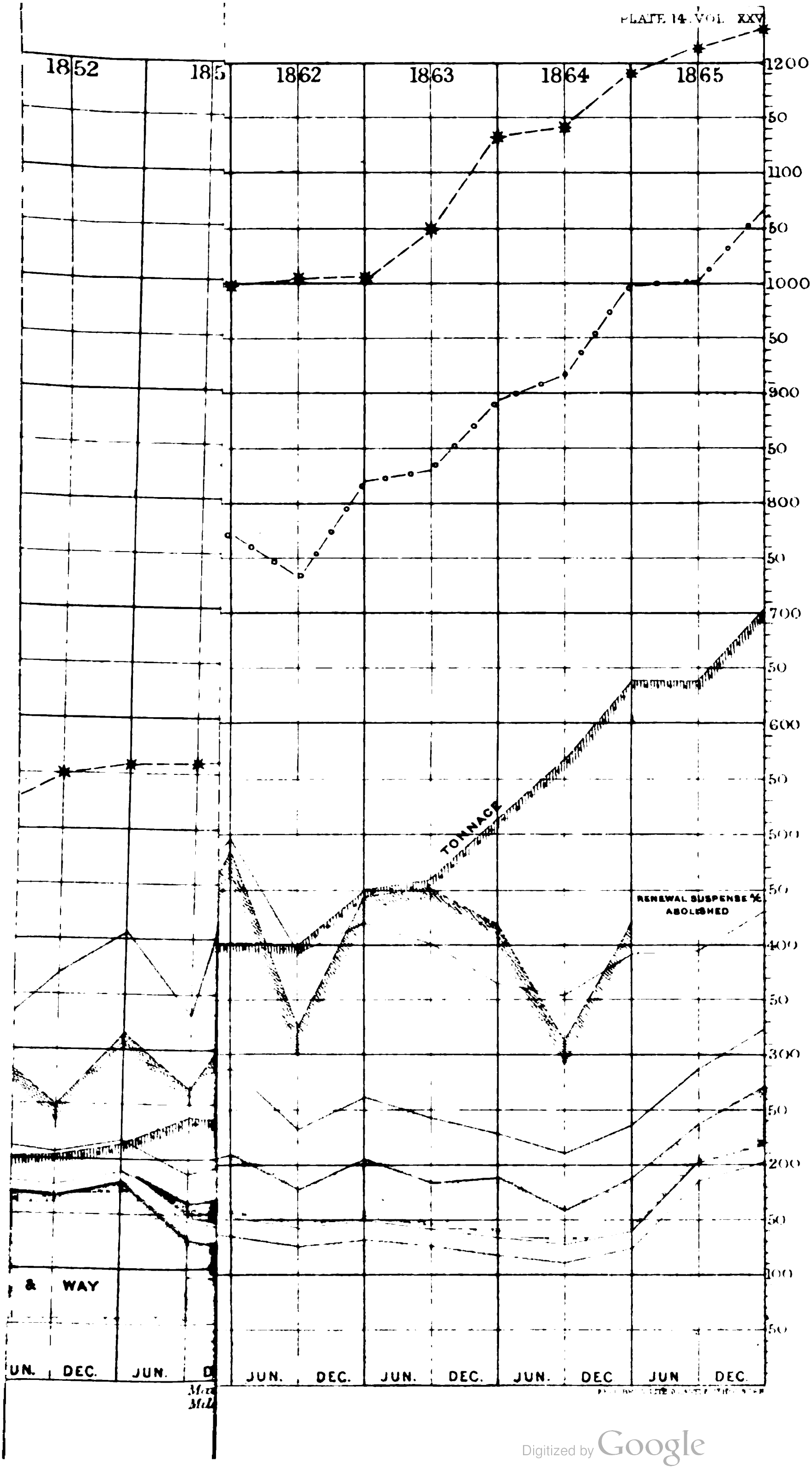
On the question of first cost, and on the relative advantages of steel at £15, and iron at half that sum, the Author does not propose at all to enter, further than to submit to the Institution the results of a most careful and elaborate calculation which Mr. Johnson (M. Inst. C. E.) has prepared (Appendix, Table 8). In this calculation he has very fairly estimated the life of an iron rail at the minimum of three years, alluded to as obtaining on portions of the Great Northern Railway, and on the other hand he has assumed the life of a steel rail at twenty years, the maximum period for which they have hitherto been able to obtain a guarantee.

From this it will be seen, that a balance of 50 per cent. is shown in favour of the steel rails, and this without taking into account the money value, which it is difficult to estimate, due to the increased safety in travelling and to the less frequent breaking up of the permanent way.

In conclusion, the Author ventures to suggest the desirability, at the present time, when the general introduction of steel rails seems probable, of arriving at something like a definite decision as to what really is the best form of section for the double-headed, bridge, and foot rails. At present not only has each Engineer his own particular views on the subject, and each railway its own peculiar section of a double-headed, bridge, or foot rail, as the case may be; but it frequently occurs that several varieties of section are in use on the same railway. It is thought that, with the aid of the experience which can now be brought to bear on this particular subject, standard types of rails might with advantage be uniformly adopted, suited to the different descriptions of traffic, and a great saving be effected, by a more judicious arrangement of the materials.

It only remains for the Author to state, that in venturing to bring this important question before the Institution, he has been influenced by an earnest desire to elicit an expression of opinion from Members who have had a large and varied experience in connection with permanent way, to whose judgment he, with all deference, submits.

The Paper is illustrated by a series of Diagrams, from which Plates 14 to 23 have been compiled, and by elaborate Tables, some of which will be found in the Appendix.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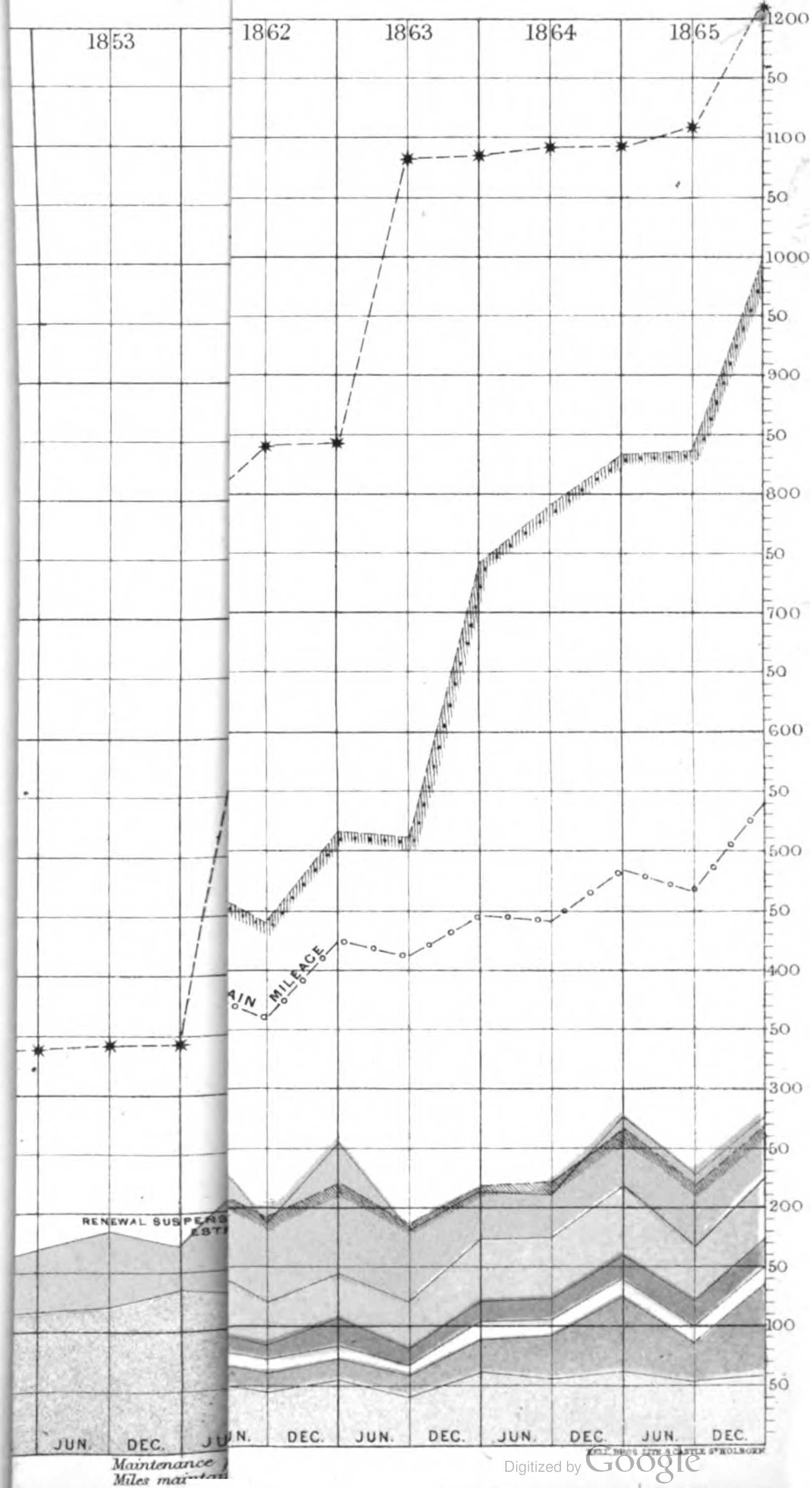

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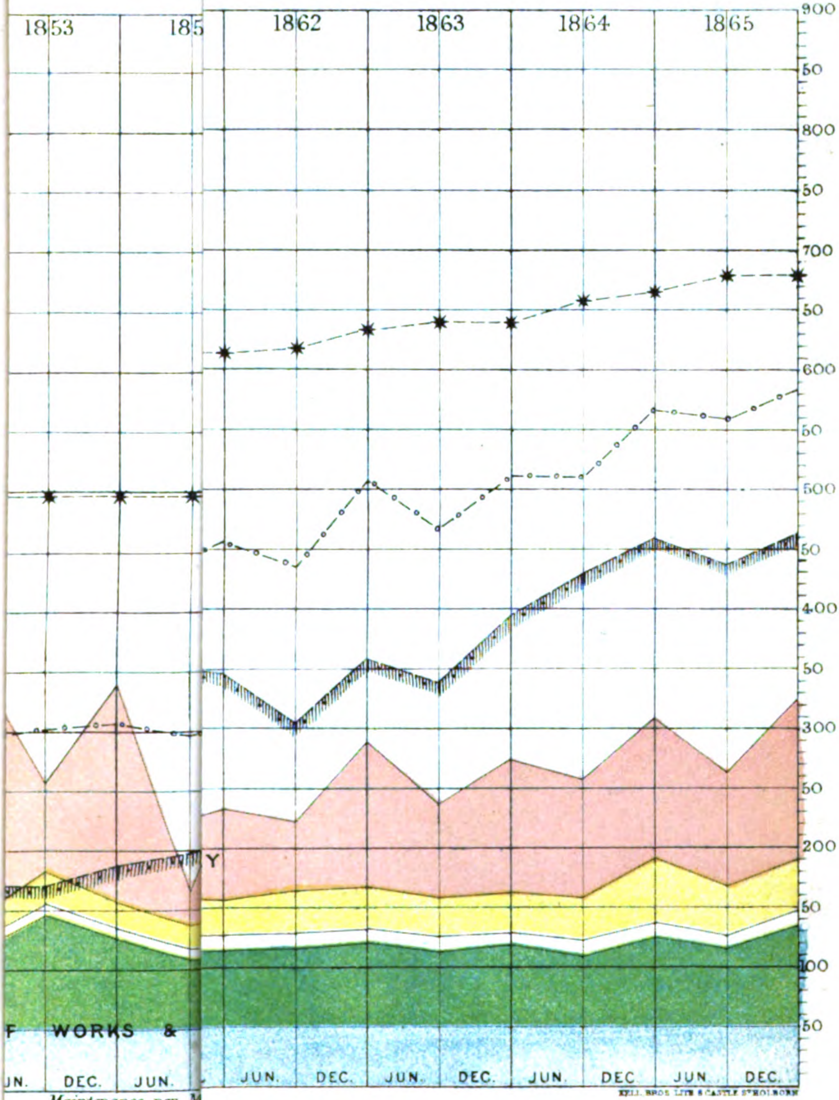

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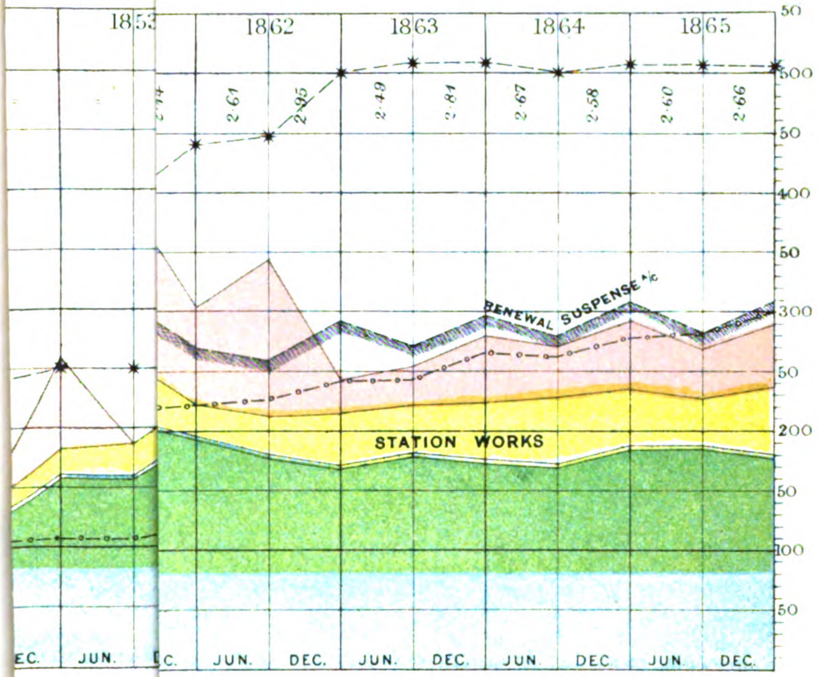

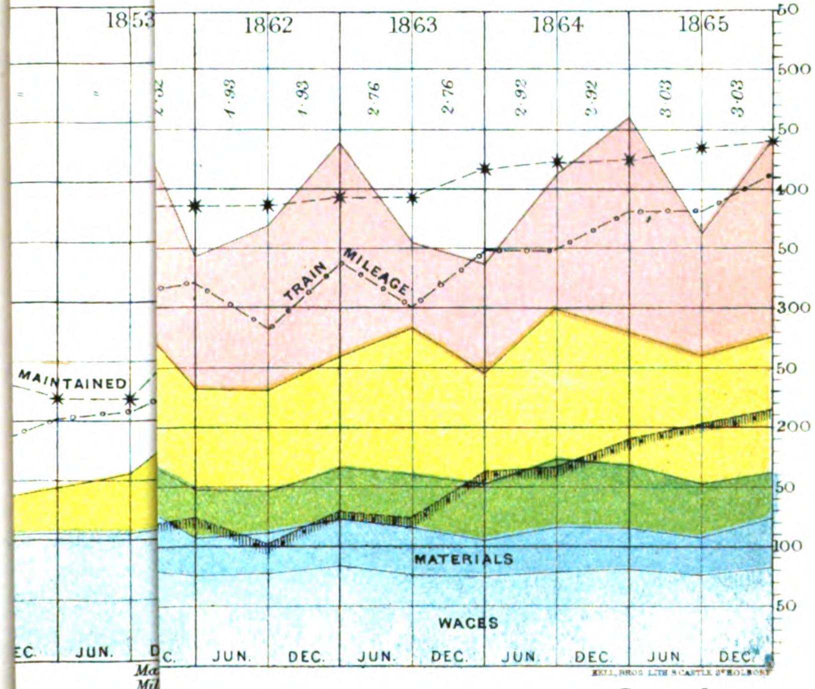

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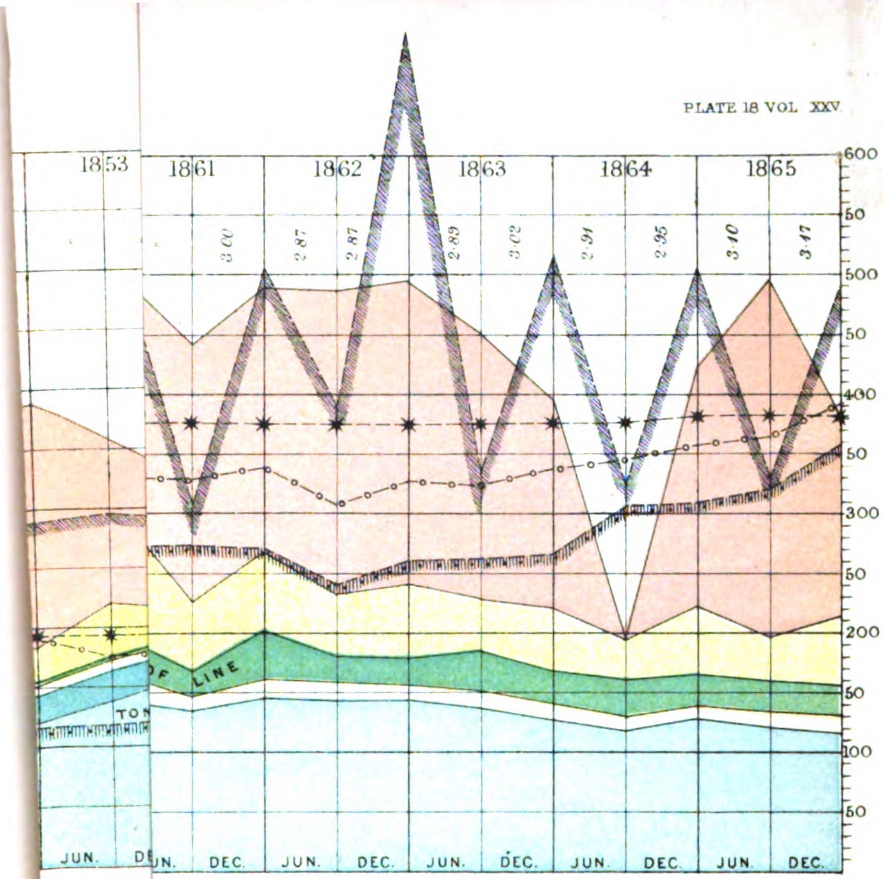
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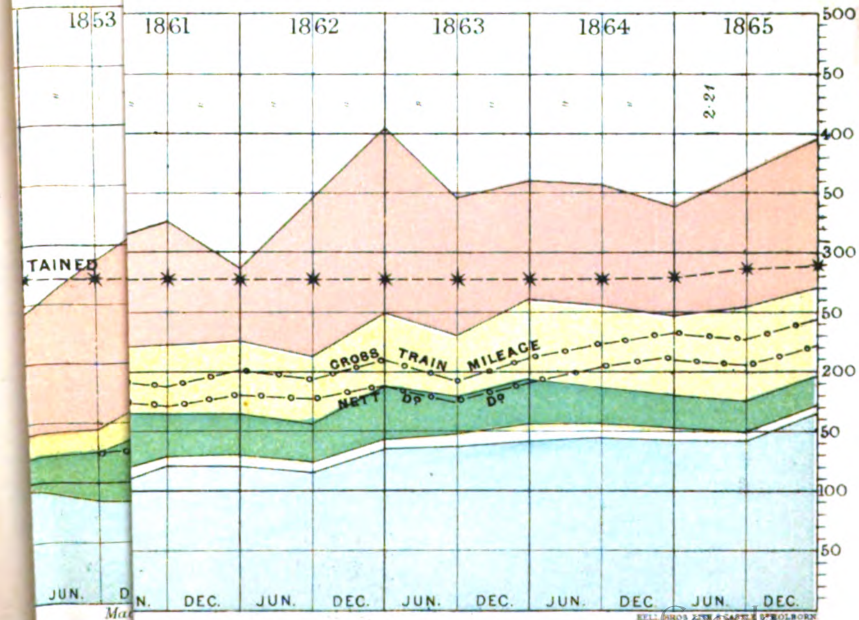
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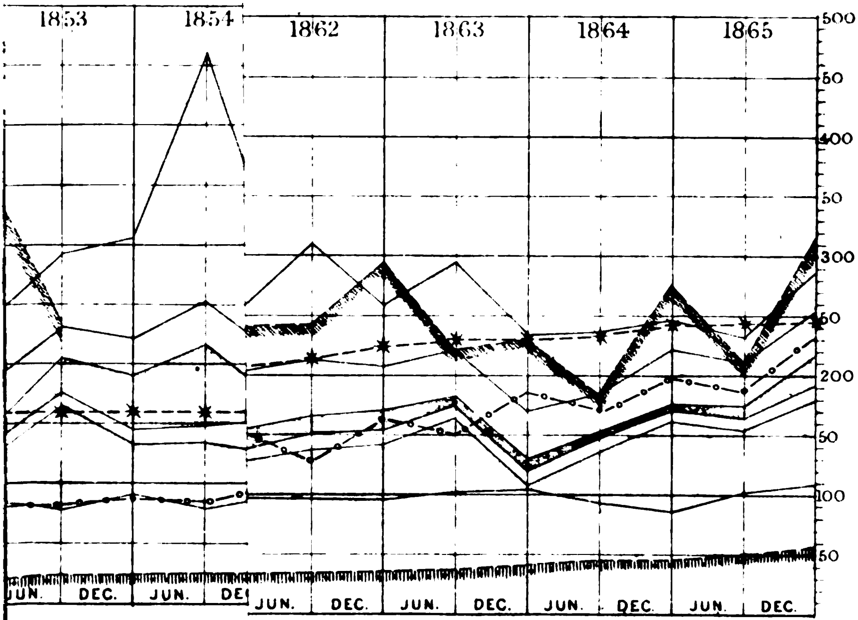

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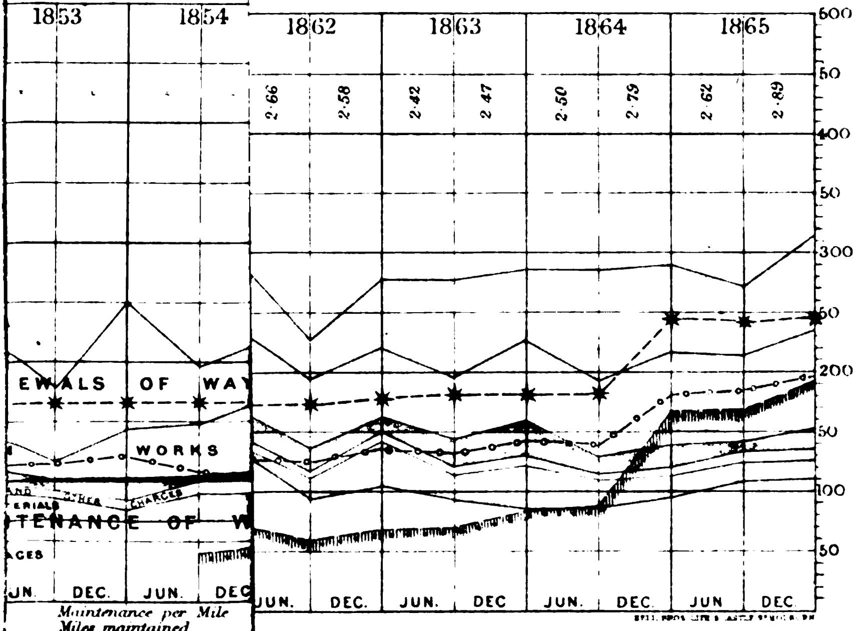

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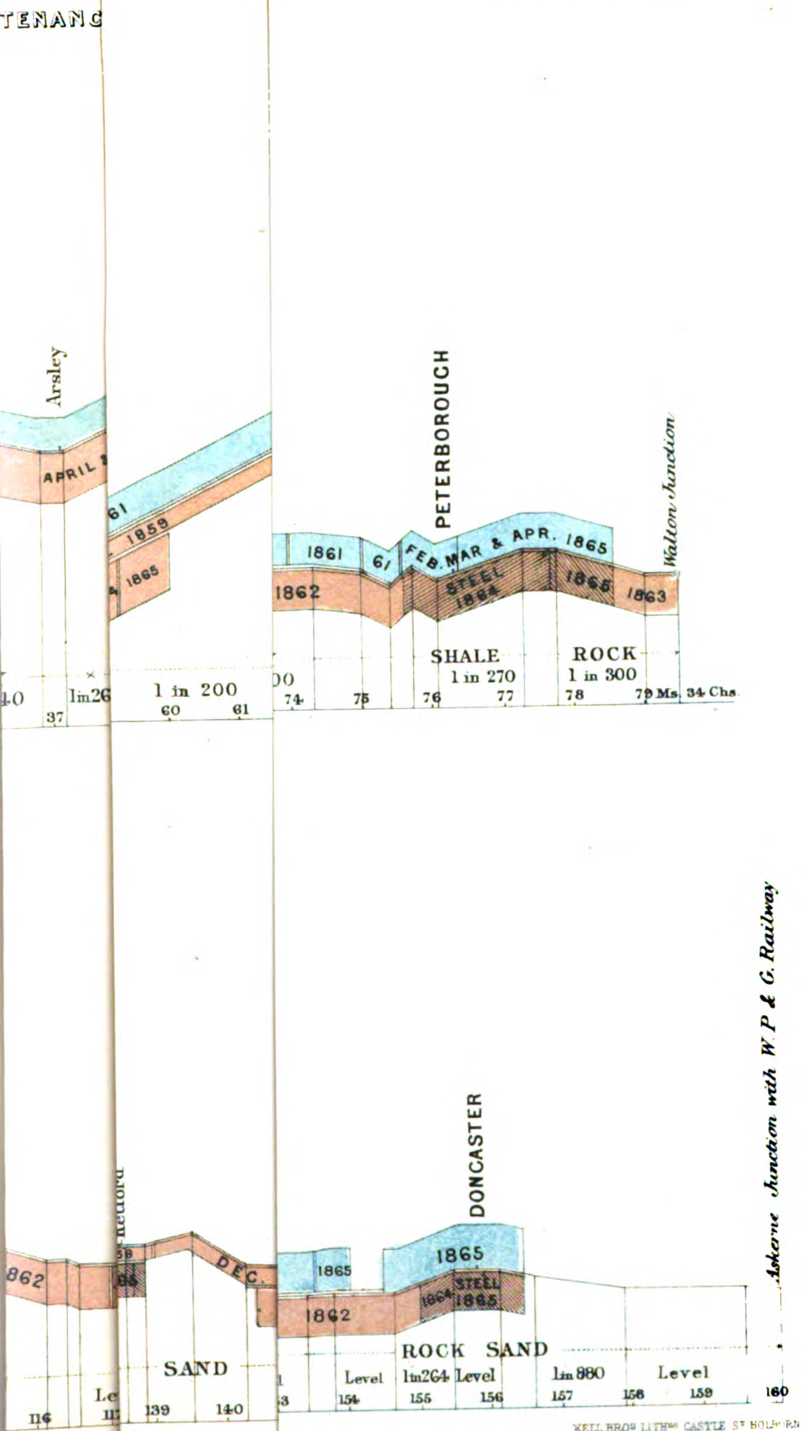
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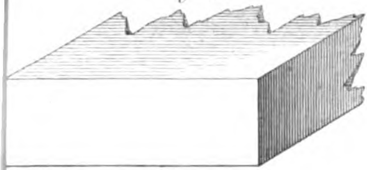
Fig: 5.



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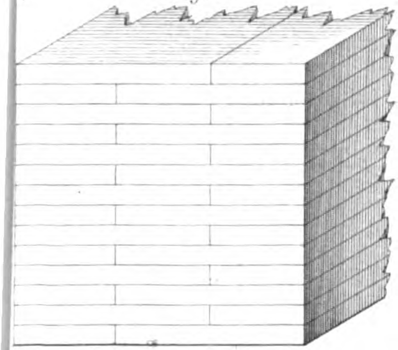

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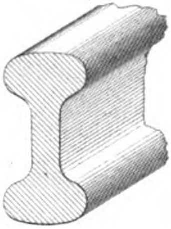

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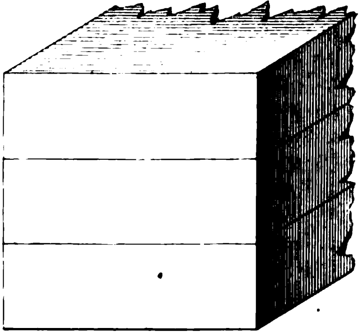

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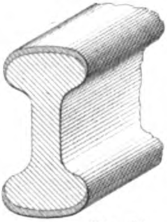

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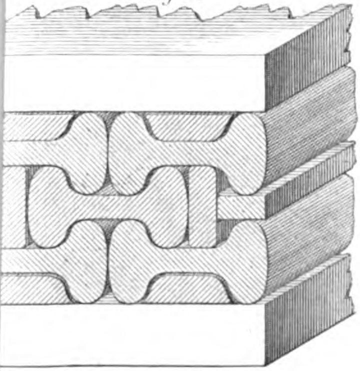

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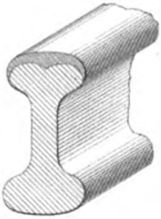

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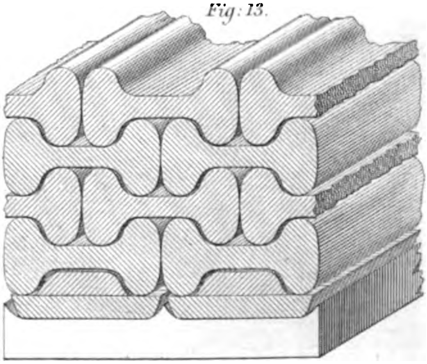

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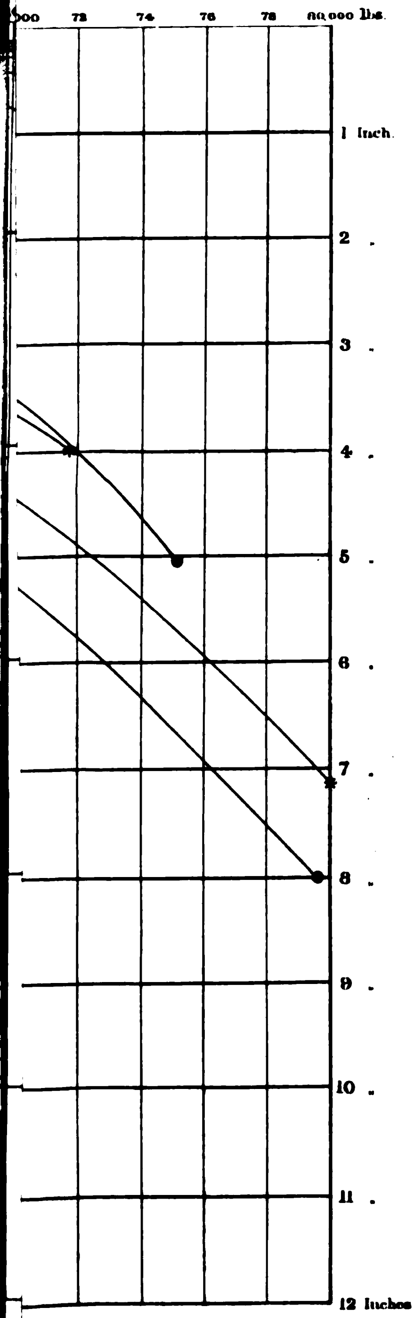

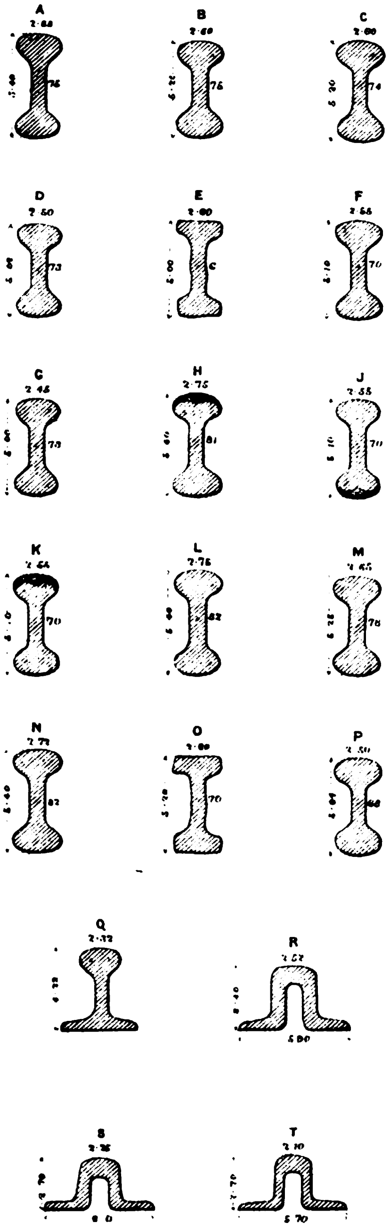

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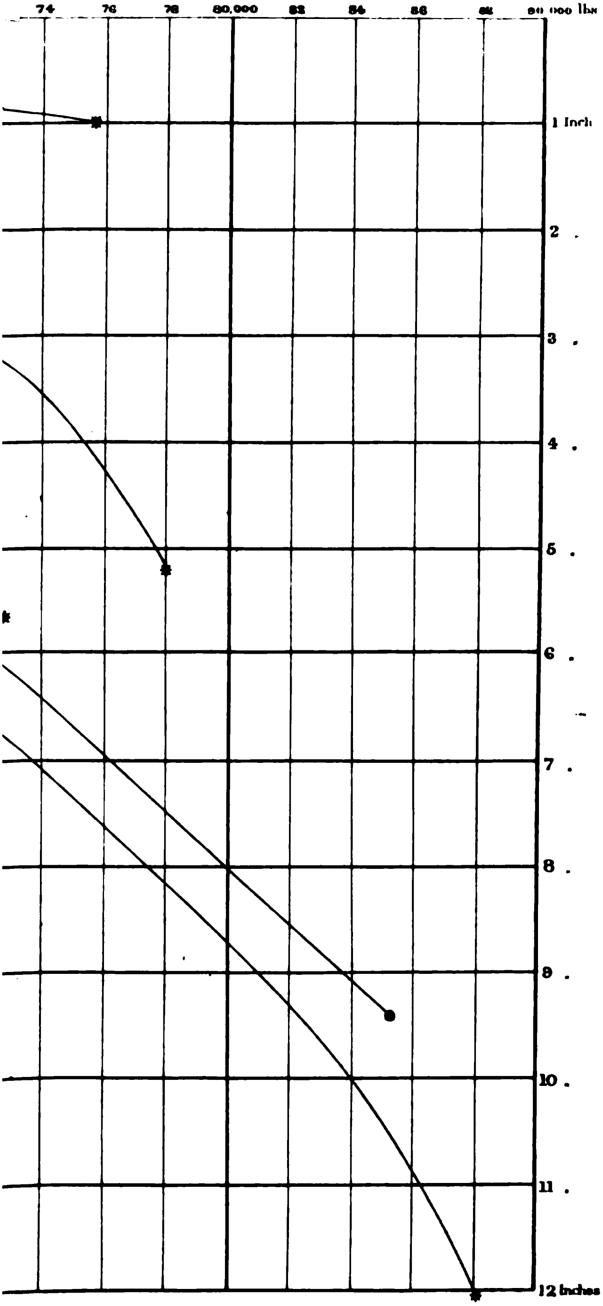

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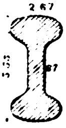

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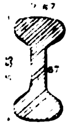

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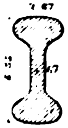

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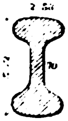

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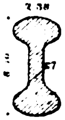

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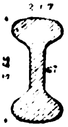

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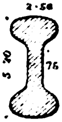

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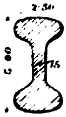

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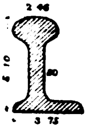
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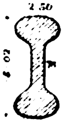

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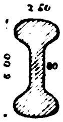

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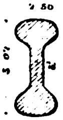

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APPENDIX.

LIST OF DIAGRAMS AND TABLES ACCOMPANYING THE PAPER.

DIAGRAMS.

1.	London and North Western Railway	Cost of Permanent Way	Two sets to different scales.
2.	North Eastern Railway	Ditto	
3.	Midland Railway	Ditto	
4.	London and South Western Railway	Ditto	
5.	Great Northern Railway	Ditto	
6.	Lancashire and Yorkshire Railway	Ditto	
7.	South Eastern Railway	Ditto	
8.	London, Brighton, and South Coast Railway	Ditto	
9.	Manchester, Sheffield, and Lincolnshire Railway	Ditto	
A.	Longitudinal section of Great Northern Railway		Ditto
B.	Ditto	Ditto	Ditto

C. D. E. F. F^a. Diagrams illustrating manufacture of iron rails.

G. H. J. K. Diagrams showing comparative results of vertical stiffness of iron and steel rails of various sections, as ascertained by Mr. Kirkaldy's testing machine.

L. Diagrams showing results of experimental rails laid down on Lancashire and Yorkshire Railway.

TABLES.

1 A to 9 A. Tabular statements showing details of cost of maintenance and renewals of way and works of the nine different railways referred to on Diagrams 1 to 9.

10 A. Statements showing number and weight of trains on Great Northern Railway from 1856 to 1865.

11 A. Statements showing number and weight of trains on Lancashire and Yorkshire Railway from 1858 to 1865.

12 A. Statement showing a comparison between guaranteed iron rails at £7 15*s.*, and estimated to last 3 years, with steel rails at £15 per ton, supposed to last 20 years.

LIST OF THE TABLES IN THIS APPENDIX.

Table 1. Summary of Mileage maintained, Increase of Mileage, and Amount expended in Renewals, with the Estimated number of Miles renewed on seven Lines, from June, 1847, to June, 1865.

„ 2. Ditto on nine Lines, from June, 1847, to June, 1864.

„ 3. Abstract showing amounts expended in Renewals of Way, Miles maintained, and Increase of Mileage, half-yearly, during a period of years, on various Railways.

„ 4. Abstract showing comparative cost per mile per annum of Maintenance of Way, Maintenance of Way and Works, and Renewals of Way, together with the cost per mile per annum of the total charges under the head of Maintenance and Renewals of Way, Works, Stations, &c., on various Railways.

5. Statement showing the duration of certain iron rails on the descending gradients of the Great Northern Railway, between Hatfield and London; and on a similar ascending gradient between the 63rd and the 66th miles.

„ 6. Statement showing the number and gross weight of trains passing over the Great Northern Railway, from Hatfield to London, 1856 to 1865.

„ 7. Statement showing the number and gross weight of trains passing over certain portions of the Lancashire and Yorkshire Railway, from 1858 to 1865; with the average life of experimental rails at various stations.

„ 8. Statement showing a comparison between guaranteed iron rails at £7 15*s*. per ton, estimated to last 3 years, with steel rails at £15 per ton, supposed to last 20 years.

„ 9. Statement showing comparative per centage on gross traffic receipts, of locomotive charges, and maintenance of way and works, for a period of years, on the Great Northern Railway.

„ 10. Experiments on Bessemer steel rail, section 34, showing the relation between the carbon contained and the resistance to pressure.

„ 11. Results of experiments to ascertain the resistance to deflection and set under a gradually increased bending strain, of rails of various materials, form, and size, made at Mr. Kirkaldy's testing works.

„ 12. Results of experiments to ascertain the resistance to deflection and set under a gradually increased bending strain, of steel rails of various forms and sizes, made at Mr. Kirkaldy's testing works.

„ 13. Statement showing the separate and collective expenditure in renewals during a period of eighteen years on various Railways.

„ 14. Statement showing the cost at the end of each year from 1 year to 20 years (including compound interest at 5 per cent. per annum), of steel and iron rails, for 1 mile of single line.

TABLE 1.

MARY of MILEAGE MAINTAINED, INCREASE of MILEAGE, and AMOUNT XPENDED in RENEWALS, together with the ESTIMATED NUMBER OF MILES ENEWED, on SEVEN of the principal RAILWAYS, from June, 1847, to June, .865, divided into Periods of Five Years.

DATE.	Mileage Maintained.	Increase of Mileage from June, 1847.	Amount expended in Renewals, in Periods of Five Years, from June, 1847.	Total Amount expended in Renewals, from June, 1847.	Estimated Number of Single Miles Renewed in Periods of Five Years.	Total Estimated Number of Single Miles Renewed from June, 1847.	Remarks.
			£.	£.			
47 June .	1,385	..	..	..	..	..	
52 „ .	2,322	937	367,203	367,203	263	262	
57 „ .	3,036	1,651	1,631,735	1,998,938	1,166	1,428	
62 „ .	3,951	2,566	2,013,086	4,012,024	1,438	2,866	
65 „ .	4,612	3,227	1,419,937	5,431,961	1,014	3,880	3 years only.

Equal to 42 *per cent. of Mileage Maintained, June,* 1865.

MARY showing the Total MILEAGE MAINTAINED, INCREASE of MILEAGE, and MOUNT EXPENDED in RENEWALS, together with the Total ESTIMATED NUMBER of SINGLE MILES RENEWED, from June, 1847, to June, 1865, as above, apportioned among the Seven Railways named in their respective order.

NAME OF RAILWAY.	Miles Maintained in June, 1847.	Increase of Mileage, from June, 1847, to June, 1865.	Total Mileage Maintained in June, 1865.	Amount Expended in Renewals from June, 1847, to June, 1865.	Estimated Number of Single Miles Renewed, from June, 1847, to June, 1865.	Remarks.
				£.		Per Cent.
London and North-Western	378	837	1,215	1,906,859	1,363	= 56
North-Eastern . . .	300	810	1,110	867,576	619	= 28
Midland	377	301	678	775,950	555	= 41
London and South-Western	117	390	507	288,661	206	= 20
Great Northern . .	..	434	434	392,992	280	= 32
Lancashire and Yorkshire	76	305	381	768,924	549	= 72
South-Eastern . . .	137	150	287	430,999	308	= 54
Total . . .	1,385	3,227	4,612	5,431,961	3,880	= 42

TABLE 2.

SUMMARY of MILEAGE MAINTAINED, INCREASE of MILEAGE, and AMOUNT EXPENDED in RENEWALS, together with the ESTIMATED NUMBER of MILES RENEWED, on NINE of the principal RAILWAYS, from June, 1847, to June, 1864, divided into Periods of Five Years.

DATE.	Mileage Maintained.	Increase of Mileage from June, 1847.	Amount expended in Renewals, in Periods of Five Years, from June, 1847.	Total Amount expended in Renewals, from June, 1847.	Estimated Number of Single Miles Renewed in Periods of Five Years.	Total Estimated Number of Single Miles Renewed from June, 1847.	Remarks.
			£.	£.			
1847 June .	1,551	..	..	..	..	..	
1852 „ .	2,650	1,099	379,222	373,222	267	267	
1857 „ .	3,376	1,825	1,758,209	2,131,531	1,256	1,523	
1862 „ .	4,337	2,786	2,109,985	4,241,516	1,507	3,030	
1864 „ .	4,881	3,330	978,883	5,220,399	699	3,729	2 years only.

Equal to 38 *per cent. of Mileage Maintained in June,* 1864.

SUMMARY showing the Total MILEAGE MAINTAINED, INCREASE of MILEAGE, and AMOUNT EXPENDED in RENEWALS, together with the Total ESTIMATED NUMBER of SINGLE MILES RENEWED, from June, 1847, to June, 1864, as above, apportioned among the Nine Railways mentioned in their respective order.

NAME OF RAILWAY.	Miles Maintained in June, 1847.	Increase of Mileage, from June, 1847, to June, 1864.	Total Mileage Maintained in June, 1864.	Amount Expended in Renewals from June, 1847, to June, 1864.	Estimated Number of Single Miles Renewed from June, 1847, to June, 1864.	Remarks.
				£.		Per Cent.
London and North Western	378	762	1,140	1,752,981	1,252	= 55
North Eastern . . .	300	795	1,095	803,265	574	= 26
Midland	377	281	658	704,915	504	= 38
London and South Western	117	385	502	264,600	189	= 19
Great Northern . .	..	421	421	335,388	239	= 29
Lancashire and Yorkshire	76	297	373	674,330	482	= 65
South Eastern . . .	137	142	279	401,728	287	= 51
London, Brighton, and South Coast . . .	121	111	232	212,954	152	= 33
Manchester, Sheffield, and Lincolnshire .	45	136	181	70,238	50	= 14
Total . . .	1,551	3,330	4,881	5,220,399	3,729	= 38

in Rene Railways during a Period of Years.

Railway.	astern Railway.		London Brighton and South Coast Railway.			Manchester Sheffield and Lincolnshire Railway.		
Amount expended in Renewals.	Mileage from 1847.	Amount expended in Renewals.	Mileage maintained.	Increase of Mileage from 1847.	Amount expended in Renewals.	Mileage maintained.	Increase of Mileage from 1847.	Amount expended in Renewals.
£.		£.			£.			£.
..	..	..	121	..	..	45	..	..
..	9	..	143	22	..	47	2	..
..	26	..	147	27	..	65	20	..
..	26	..	147	27	..	104	59	..
..	51	..	159	38	..	132	87	..
..	51	..	159	38	..	159	114	..
..	52	760	159	38	..	159	114	..
..	52	6,618	160	39	1,882	168	123	363
..	106	16,276	160	39	144	168	123	933
..	106	8,127	160	39	..	168	123	190
..	133	6,876	160	39	..	168	123	2,507
..	133	13,610	160	39	4,245	168	123	6,728
..	133	19,797	160	39	5,089	168	123	5,113
..	133	20,619	160	39	7,006	168	123	8,992
..	134	17,620	160	39	16,459	168	123	4,050
..	134	15,134	161	40	5,967	168	123	4,134
..	134	10,572	161	40	7,150	172	127	70
..	134	23,023	168	47	9,448	172	127	..
..	134	14,525	168	47	15,378	172	127	..
..	134	11,559	168	47	11,101	172	127	..
..	134	14,466	168	47	15,644	172	127	..
..	138	12,639	172	51	16,705	174	129	..
..	138	13,995	172	51	13,501	174	129	..
..	142	15,152	182	61	2,409	174	129	..
..	142	13,046	188	67	..	174	129	..
..	142	7,554	197	76	11,485	174	129	..
..	142	18,408	206	85	10,726	174	129	..
..	142	12,393	206	85	7,148	174	129	..
..	142	14,622	207	86	7,985	174	129	3,448
..	142	8,336	207	86	5,451	174	129	4,939
..	142	18,359	212	91	10,233	174	129	2,869
..	142	22,094	225	104	5,525	178	133	5,036
..	142	16,602	230	109	8,208	181	136	7,280
..	142	14,409	230	109	7,516	181	136	5,146
..	142	14,537	232	111	6,549	181	136	8,440
..	142	12,820	..	..	..	§242	197	8,394
..	150	16,451	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
		£430,999			£212,954			£78,632
	of rs .	£27,806	Average of 12½ years		£17,036	Average of 9 years .		£8,737

§ Includes South Yorkshire.

led under the head of MAINTENANCE and RENEWALS of WAY,

STERN RAILWAY.		LONDON, BRIGHTON, AND SOUTH COAST RAILWAY.				MANCHESTER, SHEFFIELD, AND LANCASHIRE RAILWAY.			
Cost of Renewals of Way per Mile per Annum.	Total Cost of Maintenance and Renewals of Way, Works, Stations, &c., per Mile per Annum.	**Cost of Maintenance per Mile per Annum.**	Cost of Maintenance and Works per Mile per Annum.	*Cost of Renewals of Way per Mile per Annum.*	Total Cost of Maintenance and Renewals of Way, Works, Stations, &c., per Mile per Annum.	**Cost of Maintenance per Mile per Annum.**	Cost of Maintenance and Works per Mile per Annum.	*Cost of Renewals of Way per Mile per Annum.*	Total Cost of Maintenance and Renewals of Way, Works, Stations, &c., per Mile per Annum.
£.	£.	£.	£.	£.	£.	£.	£.	£.	£.
..	73	..	..	..	115	..	..	..	222
..	77	..	..	..	167	..	..	..	212
..	68	..	115	..	152	..	126	..	155
..	81	**122**	158	..	205	..	93	..	112
..	101	..	124	..	166	..	68	..	82
..	118	..	..	..	182	..	57	..	73
8	144	**119**	139	..	173	..	143	..	159
70	214	**125**	137	24	217	**128**	132	4	161
134	288	**123**	146	2	197	**97**	99	11	135
67	183	**146**	153	..	191	**99**	110	2	142
51	168	**142**	153	..	187	**84**	97	30	163
101	237	**125**	136	53	235	**91**	104	80	222
147	288	**168**	197	64	295	**86**	94	61	180
153	327	**132**	179	88	310	**78**	97	107	250
130	329	**136**	208	206	457	**94**	98	48	197
112	294	**129**	144	74	283	**91**	104	49	222
78	266	**100**	106	89	251	**72**	81	1	228
169	367	**156**	175	113	353	..	163	..	183
107	331	**163**	179	183	429	..	157	..	170
85	286	**144**	164	132	378	..	159	..	174
107	308	**125**	144	186	401	..	160	..	169
92	292	**129**	137	195	396	..	157	..	173
102	285	**140**	148	157	363	..	154	..	171
109	298	**146**	158	26	248	..	168	..	186
93	270	**152**	161	..	212	..	184	..	200
54	255	**118**	126	117	295	..	176	..	191
132	365	**133**	138	104	296	..	178	..	199
89	303	**130**	150	69	286	..	222	..	243
105	324	**144**	167	77	282	**141**	154	40	263
59	283	**127**	143	53	254	**141**	164	57	296
132	340	**138**	157	96	312	**111**	132	33	229
158	407	**144**	161	49	258	**145**	158	57	278
119	346	**167**	176	71	294	**115**	139	80	277
103	362	**107**	118	65	235	**124**	153	57	286
104	359	**136**	141	56	238	**111**	124	93	285
92	339	..	..	..	..	**115**	131	70	290
115	367	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..
102	263	**136**	151	94	266	**107**	133	49	200

TABLE 5.

Statement showing the Duration of certain Iron Rails on the Descending Gradients of the Great Northern Railway between Hatfield and London; and on a similar ascending Gradient between the 63rd and the 66th Miles.

	Traffic over Gradient.	
	No. of Trains.	Tonnage.
Rails relaid, Dec. 1857 :—		
„ taken up, Dec. 1860 = 3 years	57,536	11,760,926
„ relaid, Dec. 1863 = 3 years	65,529	13,484,661
Gradient falling 1 in 200.		
Rails relaid, Dec. 1857 :—		
„ taken up, June, 1860 = 2½ years	47,445	9,679,078
„ relaid, April, 1863 = 2¾ years	58,851	12,116,382
Gradient falling 1 in 200.		
Rails relaid, Sept. 1860 „ sound, Jan. 1, 1866 } = 6 years	119,455	24,702,861
Gradient rising 1 in 200.		

TABLE 6.

STATEMENT showing the Number and Gross Weight of **TRAINS** passing over the Great Northern Railway from **HATFIELD** to **LONDON**, 1856 to 1865.

YEAR.	Trains.	Number.	Weight.	Total of all Trains per Annum.	
				Number.	Weight.
			Tons.		Tons.
1856 . .	Passengers . .	7,794	896,310	17,091	3,443,688
	Goods	9,297	2,547,378		
1857 . .	Passengers . .	7,994	919,310	17,572	3,543,682
	Goods	9,578	2,624,372		
1858 . .	Passengers . .	8,194	942,310	18,335	3,720,944
	Goods	10,141	2,778,634		
1859 . .	Passengers . .	8,394	965,310	19,018	3,876,286
	Goods	10,624	2,910,976		
1860 . .	Passengers .	8,594	988,310	20,183	4,163,696
	Goods	11,589	3,175,386		
1861 . .	Passengers . .	8,794	1,011,310	21,064	4,373,290
	Goods	12,270	3,361,980		
1862 . .	Passengers . .	9,724	1,118,260	22,107	4,511,202
	Goods	12,383	3,392,942		
1863 . .	Passengers . .	9,597	1,103,655	22,358	4,600,169
	Goods	12,761	3,496,514		
1864 . .	Passengers , .	9,767	1,123,205	23,432	4,867,415
	Goods	13,665	3,744,210		
1865 . .	Passengers . .	10,102	1,161,730	24,608	5,136,374
	Goods	14,506	3,974,644		
Total . .	Passengers . .	88,954	10,229,710		
	Goods	116,814	32,007,036		
				205,768	42,236,746

[TABLE 7.

ht of Trains passing over365 ; with the Average Life of
Ex

25 PER CENT. WORN.			ALL WORN OUT.		Per Centage, serviceable Dec. 1, 1865.
Duration of Rails.	Number of Trains.	Gross T	Number of Trains.	Gross Tonnage.	
Years.					
..	..	.	..	..	50 per cent.
..	..		104,542	19,166,356	Nil.
5	71,614	13,91	..	..	25 per cent.
2½	34,109	3,54	94,608	9,839,180	Nil.
3½	43,799	8,19	97,545	18,503,379	Nil.
2½	18,766	3,50	50,703	9,305,594	Nil.
..	..	.	62,399	12,451,784	Nil.
..	..	.	33,975	6,665,074	Nil.
4½	89,820	12,48	..	..	25 per cent.
..	..		104,542	19,166,356	Nil.
6⅛	86,940	16,68	..	..	50 per cent.
4½	58,655	6,10	116,872	12,154,740	Nil.
..	..	.	79,387	15,101,716	Nil.
..	..	.	29,397	5,433,491	Nil.
..	..	.	28,043	5,445,974	Nil.
..	..	.	110,081	15,440,259	Nil.
..	..	.	126,411	23,324,679	Nil.
3½	52,178	10,34	86,940	16,680,225	Nil.
..	..	.	58,655	6,100,120	Nil.
4½	52,924	10,00	97,545	18,503,379	Nil.
..	..	.	50,703	9,305,594	Nil.
2½	18,553	3,45	28,043	5,445,974	Nil.
..	..	.	..	..	25 per cent.
3½	89,059	16,34	65,283	31,251,932	Nil.
7½	103,182	19,48	..	..	75 per cent.
5	72,890	7,58	16,872	12,154,740	Nil.
2½	17,915	3,27	34,431	6,311,024	Nil.
3½	28,043	5,44	..	..	25 per cent.
5	110,081	15,44	..	..	50 per cent.
2½	60,437	12,04	..	..	25 per cent.
3½	89,059	16,34	3,122	38,803,128	Nil.
6⅛	94,608	9,83	6,872	12,154,740	Nil.
5	34,309	6,27	..	..	50 per cent.
2½	18,553	3,45	..	..	25 per cent.
7½	62,399	12,45	..	..	75 per cent.

2 F

[*Continued on the other side.*

ugust, 1858.	2½ Years. March, 1861.			3.	6⅙ Years. October, 1864.			7¼ Years. November, 1865.		
No. of Rails laid down.	Worn out.	Good.		Turned.	Worn out.	Good.	Turned.	Worn out.	Good.	Turned.
..	51,768			31	144,235			178,424		
..	7,195,821			59	20,261,605			25,447,601		
20	..	5		13	1	1	..	2	..	18
20	..	4		15	2	1	15	4	..	16
58	..	..		out.	..	..	..	..	..	..
20	..	11		8	2	3	11	4	..	16
28	..	21		13	3	4	14	6	2	20
52	..	14		25	4	3	27	11	..	41
78	..	66		14	6	40	21	12	12	36
..	60,437			42	146,912			173,907		
..	12,041,870			76	29,431,596			35,052,063		
14	..	7		6	2	..	11	8	..	All.
78	8	41	1	28	40	..	32	51	..	All.
46	..	42		6	16	14	11	18	14	21
..	62,323			11	165,283			203,122		
..	11,369,773			79	31,251,932			38,803,128		
8	4	1		..	..	..	..	..	..	..
8	3	..		..	..	..	..	..	..	..
8	1	4		5	2	1	..	All.	..	..
8	3	1		.. gone.	7	..	..	All.	..	..
8	2	..		.. gone.	All.	..	..	..	..	..
8	2	..		.. gone.	All.	..	Nearly gone.	..	..	..
2	..	1		1	1	..	1	All.	..	..
..	66,854			41	184,871			226,584		
..	9,442,058			89	26,132,292			32,121,972		
12	9	..		..	..	..	..	..	..	..
10	2	4		..	..	..	..	..	..	..
..	36,574			14	86,940			103,182		
..	7,382,010			51	16,680,225			19,488,540		
10	All injured.		A	9	All.	..	..	..	..	..
10	..	2		4	2	..	5	4	..	6
10	..	6		4	..	..	6	..	..	All.
10	..	5		1	..	..	3	..	..	6
10	..	6		2	..	2	4	..	..	All.
20	All good.			9	1	8	3	2	..	7

2 G

[*Continued on the other side.*

ILS at £7 15s. 3 Years, with STEEL RAILS at £15 per Ton,
supposed to I

£.	s.	d.		£.	s.	d.	£.	s.	d.	
07	10	0								
58	16	0								
15	12	9	1,7							
62	0	0								
80	2	0	1							
..				393	0	9				
07	10	0								
58	16	0								
66	18	8	1,6							
62	0	0								
60	15	0	1							
..				224	19	8				
07	10	0								
58	16	0								
38	9	6	1,5							
62	0	0								
44	0	10	1							
..				79	16	4				
007	10	0								
158	16	0								
227	10	0	1,3							
62	0	0								
29	12	0								
..				54	8	0				

H

[Continued on the other side.

TABLE 9.

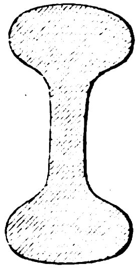
STATEMENT showing COMPARATIVE PER CENTAGE on GROSS TRAFFIC RECEIPTS, of LOCOMOTIVE CHARGES and MAINTENANCE of WAY and WORKS, for a Period of Years, on the Great Northern Railway.

DATE.		Per Centage on Locomotive Charges.		Per Centage on Maintenance of Way and Works.	
June	1851	17·03		3·23	
December . . .	1851	17·35	34·38	4·95	8·18
June	1852	..		..	
December . . .	1852	14·24		4·80	
June	1853	14·54		4·86	
December . . .	1853	13·20	27·74	6·37	11·22
June	1854	15·61		9·12	
December . . .	1854	15·18	30·79	7·30	16·42
June	1855	17·04		8·11	
December . . .	1855	15·95	32·99	7·42	15·53
June	1856	16·31		8·69	
December . . .	1856	14·50	30·81	7·73	16·42
June	1857	15·64		9·54	
December . . .	1857	14·58	30·22	9·92	19·46
June	1858	16·88		10·18	
December . . .	1858	15·14	32·02	8·46	18·64
June	1859	15·89		10·44	
December . . .	1859	13·78	29·[illegible]	8·74	19·18
June	1860	16·10		9·32	
December . . .	1860	14·51	30·61	10·40	19·72
June	1861	16·32		9·80	
December . . .	1861	14·10	30·42	8·74	18·54
June	1862	15·50		8·98	
December . . .	1862	14·76	30·26	9·22	18·20
June	1863	15·24		10·65	
December . . .	1863	13·93	29·17	9 82	20·47
June	1864	15·80		10·74	
December . . .	1864	14·70	30·56	10·08	20·82
June . . .	1865	16·94		9·99	

TABLE 10.

EXPERIMENTS on BESSEMER STEEL RAIL, Section 34, showing the Relation between the Carbon contained and the Resistance to Pressure.

The Rail was for the Great Indian Peninsular Railway Company, and the Experiments were made under the direction of Mr. G. Berkley, M. Inst. C.E., in August, 1864. The weight of Rail is 86 lbs. per yard. Distance between points of support = 3 feet 7½ inches.



Bessemer Steel Rail, made for the Great Indian Peninsular Railway—¼ full size.

Tons.	1. Carbon = 40 per Cent.		2. Carbon = 46 per Cent.		3. Carbon = 49 per Cent.		4. Carbon = 50 per Cent.		5. Carbon = 55 per Cent.		Tons.
	Deflection.	Per set.	Deflection.	Per set.	Deflection.	Per set.	Deflection.	Per set	Deflection.	Per set.	
5	·04	·00	·03	·00	·04	·00	·02	·00	·02	·00	5
10	·06	·00	·05	·005	·065	·00	·045	·00	·04	·00	10
12½	·08	·005	·07	·01	·08	·00	·06	·00	·055	·00	12½
15	·10	·01	·09	·012	·10	·00	·08	·00	·07	·00	15
17½	·127	·02	·12	·02	·12	·005	·10	·00	·08	·00	17½
20	·18	·05	·14	·05	·14	·01	·11	·00	·10	·00	20
22½	·32	·18	·36	·14	·165	·03	·13	·01	..	..	22½
25	·56	.40	·47	·32	·26	·10	·20	·06	·165	·04	25
27½	·83	·65	·76	·59	·42	·24	·34	·175	..	..	27½
30	1·10	·90	1·03	·83	·60	·40	·52	·33	·44	·27	30
32½	1·53	1·30	1·34	1·12	·825	·60	·75	·54	..	..	32½
35	1·96	1·71	1·66	1·41	1·05	·81	·97	·74	·79	·585	35
37½	3·00	2·27	2·17	1·80	1·33	1·06	1·21	·95	..	..	37½
40	3·94	3·74	2·64	2·34	1·64	1·35	1.45	1·18	1·37	1·11	40
42½	..	..	..	..	1·99	1·68	1·79	1·49	..	..	42½
45	..	..	..	..	2·45	2·11	2·16	1·83	2·14	1·83	45
47½	..	..	..	..	3·25	2·87	2·73	2·37	..	..	47½
50	..	..	..	..	4·18	3·77	3·68	3·28	3·42	3·06	50
52½	..	..	..	..	..	..	4·68	4·28	4·40	4·02	52½

JOHN BROWN and Co., Atlas Works, Sheffield.

DEFLE hes. Made at DAVID KIRKALDY'S Test ondon, March, 1866.

								ate Strain.		
3,000		54,000	56,000	58,000	60,000	62,000	64,000	Per Square Inch.	Area in Square Inches.	Remarks.
								lbs.		
·002	32	1·59	1·79	2·20	2·54	2·97	3·	10,453	7·67	Snapped.
..		1·38	..	..	..	2·61	..	..	..	
·012	8	1·96	2·31	2·59	2·98	3·35	3·	10,281	7·72	Cracked and Canted.
..		..	..	..	..	..	.	.	..	
·011	61	1·19	1·33	1·54	1·75	2 04	2·	10,334	7·25	Canted.
..		·755	..	..	..	1·56	.	..	..	
·008	10	1·43	1 65	1·97	2·15	2·45	2·	10,061	7·11	Snapped.
..		·948	..	..	1·64	..	.	..	..	
·000	9	1·80	2·05	2·43	2·74	3·25	3·	10,677	6·55	Canted.
..		1·41	..	..	2·28	..	.	..	..	
·009	22	6·04	6·72	7·38	8·14	9·08	.	8,263	7·53	Canted.
..		..	..	..	..	..	.	..	..	
·007	30	·745	·864	..	..	..	.	8,504	6·75	Snapped.
..		·285	..	..	..	..	.	..	..	
·005	8	6·85	7·96	9·14	10·17	..	.	7,639	8·11	Snapped.
..		..	..	..	..	..	.	..	..	
·000	54	8·78	9·82	..	..	..	.	7,651	7·48	Steel cracked. Iron entire.
..		..	..	..	..	..	.	..	..	
·004		..	..	..	..	..	.	6,854	7·48	Steel entire. Iron torn.
..		..	..	..	..	..		..	..	
·015		..	..	..	..	..		6,245	8·25	Cracked and Canted.
..		..	..	..	..	..		..	..	
·008		..	..	..	..	..		6,134	8·17	Snapped.
..		..	..	..	..	..		..	..	
·012		..	..	..	..	..		5,703	8·29	Canted.
..		..	..	..	..	..		..	..	
007		..	..	..	..	..		6,193	7·02	Canted.
..		..	..	..	..	..		..	..	
018		..	..	..	..	..		5,230	6·83	Torn.
.		..	..	..	..	..		..	..	
23		..	..	..	..	..		4,915	5·89	Snapped.
.		..	..	..	..	..		..	..	
41		..	..	..	..	..		2,374	7·75	Cracked through the bolt holes and then torn asunder.
.		..	..	..	..	..		..	..	
88		..	..	..	..	..		1,960	5·57	
17		..	..	..	..	..		..	..	
94		..	..	..	..	..		1,970	4·18	
..		..	..	..	..	..		..	..	

[TABLE 12.

CE to DEF inches. Met, London, April, 1866.

						Ultimate Strain.		Area in Square Inches.	Remarks.
	9,000	56,000	58,000		88,000	Total.	Per Square Inch.		
						lbs.	lbs.		
2	·044	2·80	3·28	84	11·85	88,736	10,476	8·47	Snapped.
	·005	..	..	.	..	..	..	..	
8	·052	2·34	2·65	.	..	85,480	10,092	8·47	Canted.
	·009	..	..	.	..	..	..	..	
2	·032	·429	·460	.	..	77,744	9,178	8·47	Snapped.
	·000	·087	..	.	..	..	..	..	
8	·052	1·12	1·28	.	..	78,096	10,195	7·66	Snapped.
	·007	..	..	.	..	..	..	..	
2	·054	1·95	2·26	.	..	73,248	10,434	7·02	Snapped.
	·706	..	..	.	..	..	..	..	
2	·038	3·08	3·45	.	..	67,280	7,943	8·47	Canted.
	·003	..	..	.	..	..	..	..	
8	·051	7·70	8·33	.	..	64,000	8,020	7·98	Canted.
	·004	..	..	.	..	..	..	..	
1	·051	4·40	5·02	.	..	63,616	8,860	7·18	Twisted.
	·006	..	..	.	..	..	..	..	
9	·056	6·31	7·04	.	..	63,648	9,053	7·03	Canted.
	·008	..	..	.	..	..	..	..	
8	·051	9·61	10·82	.	..	60,976	8,422	7·24	Canted.
	·005	..	..	.	..	..	..	..	
8	·056	7·85	8·78	.	..	59,288	7,650	7·75	Canted.
	·006	..	..	.	..	..	..	..	
7	·058	..	..	.	..	55,040	7,602	7.24	Canted.
	·007	..	..	.	..	..	..	..	

te and Collective dermentioned Railways.

WAY.	No	RAILWAY.		LANCASHIRE AND YORKSHIRE RAILWAY.			
quivalent to Miles of Single Line.	Miles maintained.	nount pended in Renewals.	Equivalent to Miles of Single Line.	Miles maintained.	Increase of Mileage from 1847.	Amount Expended in Renewals.	Equivalent to Miles of Single Line.
		£.				£.	
..	300	..	..	76	..	..	..
127	335	..	..	195	119	72,169	52
444	720	1,625	8	252	176	145,932	104
459	848	0,187	164	373	297	293,240	209
333	1,110	1,180	108	381	305	257,583	184
1,363		2,992	280			768,924	549
					72·047		

SOUTH EASTERN RAILWA				
Increase of Mileage from 1847.	Amount Expended in Renewals.	nt s le	Per Centage, &c. Double Mileage.	PERIOD.
	£.			
..	..		..	
133	38,657	7	5·038	5 years.
134	160,925	6	18·602	5 years.
142	134,504	7	17·373	5 years.
150	96,913	8	10·479	3 years.
	430,999	8	40·208	18 years.
53·659				

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				Per Ton.											
£7.				£8. 10s.			£9.			£9. 10s.			£10.		
.	s.	d.		.	s.	d.	£.	s.	d.	£.	s.	d.	£.	s.	d.	
35	5	0		31	6	4	142	7	8	153	9	0	164	10	3	1
72	5	3		64	18	3	287	1	2	309	4	1	331	6	11	2
11	4	6		00	19	0	434	3	11	467	8	10	500	13	9	3
52	6	9		39	12	3	583	19	10	628	7	5	672	15	0	4
95	16	2		81	2	0	736	13	0	792	4	0	847	15	0	5
41	17	2		25	11	11	892	7	5	959	2	11	1,025	18	4	6
19	4	4	1	73	6	6	1,051	7	0	1,129	8	9	1,207	9	8	7
00	8	11	1	25	6	8	1,213	14	11	1,303	6	4	1,392	14	5	8
85	16	9	1	79	7	3	1,380	4	1	1,481	0	9	1,581	17	5	9
75	14	1	1	74	13	0	1,591	12	0	1,708	10	10	1,825	9	7	10
70	7	1	1	75	8	3	1,808	14	8	1,942	1	0	2,075	7	2	11
70	2	9	2	81	19	9	2,031	19	4	2,181	18	10	2,331	18	3	12
03	18	1	2	94	14	3	2,261	13	3	2,428	12	1	2,595	10	11	13
44	7	2	2	13	19	5	2,498	4	4	2,682	9	2	2,866	14	0	14
91	18	8	2	40	2	4	2,742	0	5	2,943	18	5	3,145	16	4	15
47	2	0	3	73	11	8	2,993	9	10	3,213	9	3	3,433	7	9	16
10	6	7	3	15	12	1	3,252	19	11	3,491	10	10	3,729	18	5	17
82	2	2	3	64	3	1	3,521	8	6	3,778	13	7	4,035	18	9	18
91	9	6	4	58	13	7	3,839	17	7	4,121	1	3	4,402	4	11	19
11	6	0	4	63	13	1	4,169	8	9	4,475	4	2	4,780	19	6	20

t includes—
yard, say 118 t
„ 130
h year's propor he Guaranteed Period or assumed Life.
case of Iron Ra
e Value of the

Mr. R. PRICE WILLIAMS said, as many of the experiments recorded in the Appendix had been completed since the Paper was written, and as the results had, he thought, an important bearing upon the subject dealt with, it had been considered desirable that he should briefly explain the diagrams, Plates 22 and 23, which embodied the results of various tests. In those diagrams, the uppermost horizontal line was divided by a scale of equal parts representing the pressure applied at the centre between the bearings, the vertical line similarly representing a scale of deflections in inches; but inasmuch as the latter was too large to allow of the results being shown upon one diagram, Mr. Kirkaldy determined, when he got to a certain point disappearing below the horizon, to reduce it, so that the other half of the diagram was to one-half the scale. In this way the whole of the deflections were shown on one diagram. In adopting 8 feet lengths of rails and 5 feet bearings, he had followed the system carried out by Mr. Francis Fox, M. Inst. C. E., in his interesting series of experiments on the vertical stiffness of rails.[1] There was this advantage in the 5 feet bearings—that the depth of the rail was just $\frac{1}{12}$th of the distance between the supports, being about the proportions of ordinary girders. The rails experimented upon were not sample rails obtained from the makers, but were chiefly supplied by Mr. Johnson, M. Inst. C.E., the engineer of the Great Northern Railway, and a few by Mr. Ramsbottom, M. Inst. C.E., from Crewe.

Commencing with the iron rails, the curved lines marked with the letters T, S, and R (Plate 22), represented the deflections of three sections of the bridge form of rail, and showed the least favourable results. For instance, the rail marked R, with a sectional area of 7·75 square inches, cracked through the bolt-holes with only an ultimate strain of 2,374 lbs. per square inch. The other two—which it would be seen were lighter rails—broke through the bolt-holes with considerably less ultimate strain.

The outline, Q, showed the deflection and point of fracture of a flange-rail of a smaller section, viz., 5·89 square inches; it snapped suddenly with the comparatively small weight of 4,915 lbs. per square inch, and showed a deflection of more than 3½ inches. The outline, P, represented the deflection of a light-sectioned Ebbw Vale double-headed rail of 6·83 square inches sectional area, the star showing the point of fracture: it broke with an ultimate strain of 5,230 lbs. per square inch. The next rail, marked M, was a heavy section of the same make, 8·17 square inches sectional area, and it suddenly snapped with 6,134 lbs. per square inch, and showed a deflection of 6·95 inches. There was a curious instance of two exactly similar deflections of two different rails; viz., P, which showed the ultimate breaking strain of the Ebbw Vale rail, and K, that of a steel-topped rail, which continued, it would be observed, in its deflection to the bottom of the diagram, and broke through the iron with an ultimate strain of 51,200 lbs., and the large deflection of 10·25 inches.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xx., pp. 259-274.

The next outline, marked L, showed the deflection and point of fracture of the present section of rail adopted by the London and North Western Railway, at Crewe; it cracked and canted with a strain of 6,254 lbs. per square inch. In form and sectional area this rail was nearly identical with the one last mentioned.

The next three deflections, marked H, J, and K, were those of steel-topped rails made after the plan adopted at Crewe. These showed higher results per square inch of ultimate strain than any of the iron rails. In the first instance the steel was subjected to compression, with 6,854 lbs. ultimate strain per square inch, when the iron was broken through, and torn up along the web, while the steel remained entire.

The next sample, marked J, was treated in the reverse way, the least favourable, of course, to the steel. The steel in this case was cracked through, the iron remaining intact.

He now came to the steel rails. The one marked G was peculiar only for the remarkably slight deflection it showed, amounting to only 0·86 of an inch, with an ultimate strain of 8,504 lbs. per square inch, and it broke suddenly. In connection with this hard form of steel rail he should mention that, through the kindness of Mr. Bragg, of the firm of Messrs. John Brown and Co., he had been supplied with the results of an interesting series of experiments, carried out, he believed, at the request of Mr. G. Berkley, and on which he hoped to hear something further, showing, as they did, the remarkable influence of a certain small increase in the proportion of the carbon (*Vide* Appendix, Table 10). The next rail, by the same makers, was equally remarkable for the other extreme of softness: for under a pressure of 8,263 lbs. per square inch it showed the large deflection of about 9¾ inches, and was canted and bent, but could not be broken.

The rails marked A, B, and D represented what he considered might fairly be taken as the average make of steel rails. The rail marked A, which showed the highest result of all the rails experimented upon, was supplied by Mr. Ramsbottom, from the Crewe works. It broke with an ultimate strain of 82,000 lbs. The sectional area was 7·67 square inches, and the ultimate strain per square inch was 10,453 lbs. The deflections of the next three rails, B, C, and D, it would be observed, preserved nearly the same outlines, and, in fact, broke with only a slightly less ultimate strain. There was one rail, however, marked E, which had not yet been referred to, and mention of which had been purposely reserved to the last: this was the famous Chalk Farm rail alluded to in the Paper. It occurred to him that it would be exceedingly desirable to ascertain, if possible, to what extent the serviceableness of this rail had been affected, by the enormous amount of traffic to which it had been subjected; and he asked Mr. Bessemer, to whom the rail belonged, to allow it to be submitted, along with other rails, to Mr. Kirkaldy's testing machine. At the time this rail was lying face to face with the seventeenth iron one, and it struck him, on examining it, that, if put to the test, it would still be found to have more life in it than any new iron rail. The result showed that, although it had sustained the enormous traffic of nearly 100,000,000 tons in three years, and had been worn away to the extent of more than a quarter of an inch, yet, after a continued strain of upwards of 10,677 lbs. per square inch, and after bending to the utmost limits allowed by the machine, it finally refused to be subjected to any further testing, and was canted in the manner shown in the rail itself which he exhibited.

Mr. W. P. STRUVÉ said, in speaking of the life of rails, it might be interesting if he described the process of manufacture which was adopted at the Cwm Avon Works in Glamorganshire, belonging to the Governor and Company of Copper Miners of England. These were not the largest works in Wales, but they made annually about 30,000 tons of finished rails, tin plate, and smelted and manufactured copper on a large scale. The process adopted was that of making unlaminated iron. The bloom now shown represented a block of unlaminated wrought iron, made directly from the refinery in the ordinary way, and after that run into another refinery, the refining process being continued till it became wrought iron. It was then taken out in a lump of 300 lbs. or 400 lbs. and placed under the steam-hammer. After being worked into a bloom, it was put into a heating furnace, re-heated and re-hammered two or three times, till it came out in the state it then was. In that condition it was ready to be rolled into slabs 2 inches or 3 inches thick. This unlaminated metal was used at these works for the purpose of 'topping' iron rails. The process of making the iron was a simple one, and not costly: one steam-hammer, two refineries, and two heating furnaces being capable of making about 60 tons of blooms per week. He could not at present give any important results of experience with this iron, because the process had only been introduced during the last twelve months. Some rails of that manufacture had been laid in the neighbourhood of London, and those which had been put down at Paddington were subjected to a traffic of 130 trains per day over them; and after having been down about twelve months, they as yet showed no signs of wear. At Cwm Avon he had placed them against rails made under ordinary specifications, and they had worn out two sets of the latter already.

With regard to the life of a rail, and especially of the Bessemer rail at the Chalk Farm Bridge, he was acquainted with the Bessemer process, which produced a wonderful metal; it ought, in fact, to be called a new metal. The Bessemer rail did, however, wear out. At Chalk Farm, in the course of three years, $\frac{3}{10}$ths of an inch had been carried away under the traffic that passed over it, or equal to $\frac{1}{10}$th of an inch per annum. In the Paper which had been read, the wrought-iron rail was spoken of as having a life of three years, while to the Bessemer rail a life of twenty years was assigned. Now, $\frac{1}{10}$th of an inch per annum would in twenty years amount to 2 inches, and in time the rail would go; but, as $\frac{3}{10}$ths of an inch had been worn off in three years, he thought seven years was as long a life as could reasonably be awarded to the Bessemer rail. He thought after $\frac{3}{10}$ths of an inch of metal were carried off in three years, or equal to $\frac{7}{10}$ths of an inch in seven years, the rail ought to be put by, and it might be a question, whether it would be safe to turn a rail after $\frac{3}{10}$ths of an inch were worn off. He did not contend that the class of rail of which he spoke would last as long as the Bessemer rail; but if the former would last five years and the latter seven years, then the cost of the Bessemer rails would be about £500 per mile per annum, and that of wrought-iron rails about £350 per mile per annum, for rails weighing 85 lbs. per yard. That divided over the traffic of any railway, would give the cost for rails per train per mile. He thought, from the consideration he had given to the subject, that 3½*d.* per train per mile represented the permanent existence of a rail on a railroad for any amount of traffic, and he believed it ought to be well done for that. He did not, however, consider that the Bessemer rail could do it as cheaply; and he ventured to express the opinion, that railway companies, as a general rule, would not adopt, to any great extent, the Bessemer rail at £16 per ton. This might be a bold statement, but having had a good deal to do with the making of rails, he knew how closely Engineers looked at the price per ton. In South Wales, with all the pig-iron made there, there was scarcely any convertible into Bessemer steel; nor did he believe Bessemer steel could be welded to the ordinary wrought iron of Wales so as to make a safe weld. At the same time, he thought the Bessemer steel a most valuable metal for many purposes. If, however, an iron-master were offered 500 tons of old Bessemer rails and 500 tons of old iron rails, the latter would be the more readily taken; as he supposed old Bessemer rails would have to be put into the blast furnace, and be melted down, for conversion into something useful. After all, it came to a question of money; and it did not appear to him, that the Bessemer was likely to supersede the wrought-iron rail.

Mr. C. W. Siemens said, it had been asked, what was to be done with the Bessemer iron after it was worn out? He replied—melt it down, not in a blast furnace, but in a melting furnace, and make cast steel of it. He did not speak at hazard, for it was actually done by means of his Regenerative Gas Furnaces. M. Emile Martin was carrying out at Sireuil, in France, a process of melting scrap steel, sometimes Bessemer metal, in an open reverbatory furnace, which had been built by Mr. Siemens as a puddling furnace. This metal, when melted down, was used for steel tires of railway wheels.

With regard to the Paper generally, it contained a mass of valuable facts, which he thought would lead Engineers to a thorough knowledge of what they actually required, and that was nearly as valuable knowledge as the mode of carrying the necessary improvements into effect; because the remedy for a mechanical defect might, now-a-days, be almost regarded as the necessary consequence of its proved existence. His own interpretation of the facts and experiments brought forward in the Paper was, that instead of using laminated metal, which might be regarded as a bundle of iron wires soldered together by cinders, the metal used for rails and tires should be homogeneous; and that in order to get it thoroughly homogeneous, it ought to be cast. The Bessemer process gave a ready means of melting metal which was called steel, but which might with equal propriety be called homogeneous iron; because he believed that most of the Bessemer metal, such as was used for rails, contained not perceptibly more carbon than many ordinary sorts of iron; and if a bar of iron was melted into a homogeneous mass, the probability was the result would have been a metal not differing greatly from the Bessemer metal. In order to melt this metal, when not resulting directly from the Bessemer process, recourse must be had to another process, such as he had before mentioned. Speaking from his own experience, a ton of scrap steel could be melted with less than a ton of common slack, either on an open hearth or in crucibles; and this was, in his opinion, a satisfactory answer to Mr. Struve's objection to steel rails, the cost of remelting the steel by this process being as small as that of re-rolling iron rails.

Mr. Fowler, President, inquired whether, if the Bessemer metal could be melted and used for tires, there was any reason why the same metal should not be remade into rails?

Mr. Siemens had merely stated a fact within his own experience, but he saw not the least objection to reconvert the Bessemer rails into cast steel rails, which would certainly be improved in quality by the transformation.

Mr. Vignoles, as a very early worker in the establishment of railways, had followed the various processes with great interest, and begged to offer one or two remarks. First he would inquire whether all these experiments had been made upon the same sections of double-headed rails, or whether other sections than the double-headed rail had been tested?

Mr. WILLIAMS replied, there were various sections of rails; but in the instance of the Crewe rails, which were double-headed, they were nearly all of the same section.

Mr. VIGNOLES remarked, that he was one of those who held that the double-headed rail was not the best form of section. For this he had contended for nearly thirty years, although he had himself received a premium from the London and Birmingham Railway Company for recommending it; but he had scarcely given that opinion when he found cause to repent it. So far in practice as he had had opportunity of observing it, the double-headed rail did not answer the intention he once thought it would, and such was still the conviction of those who advocated it, viz., that they had only to turn it and make use of the lower surface. Experience showed that, after seven or eight years' wear, the double-headed rail, if turned, snapped almost immediately; and on referring to the records of the Institution, the particulars would be found of the circumstances under which double-headed rails, when turned after a few years' wear, broke suddenly. But that was not the only objection. The Author of the Paper had expressed wonder, that there had been so little improvement in the permanent way. There could be no improvement in the permanent way so long as chairs were used, a complication of construction which had been long ago abandoned in every country but England, in favour of the flat-bottomed rail. With a rail weighing 80 lbs. per yard, and chairs 35 lbs. each, it would be found that the chairs constituted about 25 per cent. of the weight of iron employed. Now, if that were applied in adding to the weight of the 82 lb. rail, a rail could be obtained of nearly 100 lbs. weight. Without going into the question of the quality of different materials, having had little or no experience in the Bessemer rails, he argued upon the principle, that the double-headed was not the best form of rail, because it necessitated the use of the chair, which involved a complication of parts, required a wooden plug to keep the rail steady, and the chairs had to be fastened to the sleepers. The fishing of the rails was the greatest improvement that had been made, but that was not an English invention, as long before it was used in this country he had seen it abroad. It made the rail continuous, while the chair led to a dislocation at every sleeper. Those who recollected the old system of construction must be aware, that the jolting was due to the chairs, and where it existed now it could be traced to the chairs. If the Author sought improvement in the permanent way, he must begin by abandoning the chair. He could understand that improvement in the quality of the iron would tend to the improvement of the permanent way; but if the weight of the chairs now in use was added to the rails, and better rails at a very little larger price were obtained, then there would result a better road that would be kept in order at less expense.

As to the iron being homogeneous: looking at the modern specifications for rails—particularly those for Russia—a guarantee of six years for the rails was required. The specifications were incompatible with anything homogeneous; as the rails were to be excessively hard at the top, and elastic, or capable of extension, at the bottom. Homogeneous iron could not fulfil those opposite conditions; and herein was the difficulty of constructing the modern rails, as it was desired that the piles should be arranged in such a way, that the fibrous parts might be at the bottom and the crystalline parts at the top. The difficulty was to make the two piles meet, and to define how far the fibrous part should extend up the stem, and how far the crystalline part should go to meet it. However desirable it might be to use homogeneous metal for rails, it would not fulfil the requirements of modern specifications.

He urged that the double-headed rail was not one which modern practice and modern simplicity required. The great essential of the permanent way of a railway was, that it should be composed of the smallest number of parts. He thought by fishing, by dispensing with chairs, and by adopting the flat-bottomed form of rail, in which the greatest strength to resist deflection was found, that the greatest improvement in the permanent way would be arrived at; but it was impossible for any one to be led away with the hope, that the cost of maintenance could be much diminished. The constant increase in the weight of engines and the weight of traffic could only be met by a certain degree of elasticity in the road. It was a fight between the rail and the train, and there must be a certain amount of residual damage, which could only be kept up by a proportional renewal and proportionate expenses. If that could be diminished in any degree it was desirable that it should be done; but he did not think the modern practice would enable the expenses of maintaining the permanent way to be reduced in any material degree.

Sir Charles Fox agreed with Mr. Siemens that, although it was a matter of great importance to get a harder and a better quality of material for these purposes, it was, in his opinion, of still greater importance to get rid of iron rails, which, from being rolled from piles of bars, were only, in fact, bundles of rods. It was not only in these two respects that he felt it important to make rails of steel and perfectly homogeneous, but he thought it was desirable if possible to diminish the weight of the rails, by the use of a superior description of metal. The top surface of a rail was that upon which the wheels ran, without the intervention of any spring or elasticity between those two things; consequently he looked upon the rail itself, particularly as iron rails were now made with a slab on the top, as an anvil by which such slab or bar was hammered by the tire; and having examined, by means of a magnifying-glass, a vast number of rails that had failed, he had found that in almost all cases of what was termed lamination, the failures had most frequently arisen from the presence of some foreign matter between the bars which formed the pile from which the rail was rolled. Foreign matters might be of many kinds—rust on the surface, or dirt collected in moving the bars about the rolling-mill; but perhaps the worst of all was, when a drop of melted fire-brick fell from the top of the furnace upon the red-hot pile, which ran over it like oil, when all the hammering or rolling in the world would not cement those bars together; but they would be, as Mr. Siemens had remarked, cemented together by cinders only. He therefore thought it was a matter of the greatest importance, not only to make rails of good material, but to make them out of one piece of metal; and for that purpose he knew of nothing better than the solid ingot obtained by the Bessemer process, which by hammering was got into a convenient size and length for rolling into a rail. In cases under his own charge, he was taking care to have a little elasticity between the tire and the body of the wheel, so as to reduce as much as possible the effect of the sledge-hammer action of the tire upon the surface of the rail.

Mr. GEORGE BERKLEY, while not intending to express an opinion opposed to that which had fallen from Mr. Vignoles, thought the present state of practice had been rather exaggerated, inasmuch as he believed there was as large, or probably a larger, number of double-headed than of Vignoles' rails being made in this country. In the south of France, he had recently seen rails not double-headed being taken up, and double-headed rails with chairs being substituted. He intended to limit the purport of his observations on this subject merely to the question of fact regarding the general adoption of one form of rail in place of the other.

With reference to the observations which had been made about the Chalk Farm rail, an erroneous impression appeared to prevail. It was asserted in the Paper, that where iron rails lasted three years steel rails would last twenty years. Mr. Struvé—having overlooked the fact, that while $\frac{3}{10}$ths of an inch were being ground away from the surface of the Bessemer steel rails at Chalk Farm, there were no less than sixteen faces of iron rail destroyed—stated that in twenty years, at the same rate of wear, 2 inches would be worn away, which being clearly inadmissible, proved that a Bessemer rail was not capable of lasting twenty years. If however it was taken into consideration, that one face of an iron rail would in that position only last $\frac{1}{16}$th part of three years, the fallacy of this argument would be apparent. Three years was not the life of an iron rail in that position, but $\frac{1}{16}$th part of three years was the life of one face of an iron rail, and the life of twenty years assumed for a steel rail in that position must be reduced in the same proportion.

With regard to the Paper itself, he thought there could be no difference of opinion as to its value, or as to the labour which had been devoted to collect, arrange, and illustrate an immense mass of facts for the benefit of the profession, nor of the modesty displayed in the manner of stating this information. The Author had been content to suggest those points which were material for discussion. There were three points which seemed to him to be prominent. The first he took to be the life of the rail. Now they were very apt to regard life as a period of years; practically he thought the Author had regarded it in the true way. The value of life was represented by the work done; the Author had, therefore, in the Appendix to the Paper, tried to show what amount of work each rail had done, what amount of abrasion it had received, and, at the same time, the circumstances which would help, or detract from, the power of that rail to withstand that abrasion were stated. That seemed to be a philosophical way of dealing with the subject; and great credit was due to Mr. Williams for the care taken in arriving at these facts, which were of peculiar value, as enabling a comparison to be instituted between iron rails and those made of Bessemer steel.

The first case given was that of the rails on the Great Northern at Barnet, the life of which was three years, with a work represented by 13,484,661 tons passing over them. Another case was that of rails which bore the passage over them of 12,451,780 tons of traffic, and attention was then drawn to the fact, that this was on an incline where the traffic was of a heavy character, travelling at a comparatively high speed. On the line where the rails were not subject to the same abrasion, and where the speed was much less, the rails bore the passage of above double the tonnage of trains passing over them. Taking that advantageous case of the 38,803,028 tons, and comparing it with the instance of the steel rail, it would be found that the steel rail, which was not yet more than half worn out, had already borne 95,577,240 tons passing over it. He should have been glad to have heard what the ballast was, and what the whole circumstances were, the form of sleepers, length of bearing, &c., in each case.

The next point the Author remarked upon was as to the form of the rail. No opinion was given as to what was considered to be the best form, but it was suggested that the best form should be determined and be universally adopted. Now he was not an advocate for fixed rules; Engineers must exercise a discretion, and, under the circumstances presented in each particular case, must determine what was the best form of rail to lay down. The opinion was, no doubt, based upon the great variety of strains which rails of different sections had, by experiment, shown themselves capable of bearing; but he thought it should be considered, that rails were designed to meet different circumstances: for instance, with longitudinal bearings a rail was required which gave a large surface on the longitudinal bearer, and which was not called upon to act as a girder. This was a shallow rail, and, if not supported by the longitudinal timber, would appear inferior to the double-headed or the Vignoles' rail, which were more adapted to act as girders supported between the points of bearing. The statistics of the Great Western Railway showed, that rails of that form, which gave an inferior result, when tested as girders, had yet borne the traffic just as well as other forms of rail. Therefore he did not think one form was necessarily preferable to another, neither was it admissible to say—"This or that was the best form of rail, and ought to be adopted under all circumstances."

He had looked carefully through the Appendix, with the view of ascertaining if he could discover sufficient evidence of the superior strength of the Bessemer rails, and, if so, in what degree they possessed it? He had found only one instance where there was the same section of rail made of iron and of steel. Where that was the case, the test seemed to him to be, as a comparative test, a fair one. That was so with the Crewe new rails. The Crewe new rail, tested on 5 feet bearings, bore a strain of 10,453 lbs., when made of Bessemer steel, while the same section of Crewe new iron rail bore only 6,245 lbs. There was in this a manifest advantage in the strength of the Bessemer steel rail of something like 70 per cent.

He had abstracted from numerous experiments made for him upon rails the following average results:—

Experiments with Iron Rails.

Weight of Rail.	Makers' Name.	20 Tons.		30 Tons.			
		Def.	Per. Set.	Def.	Per. Set.	Def.	Per. Set.
		Inches.	Inches.	Inches.	Inches.		
68 lbs.	Ebbw Vale Co.* . . .	·72	·58	2·13	1·96		
do.	Bolckow, Vaughan, and Co.†	·67	·56	1·81	1·67		
	Patent Shaft Co.‡ . . .	·52	·37	2·71	2·58		
	3)	1·91	1·51	6·65	6·21		
	Average . . .	·63	·50	2·21	2·07		

* 82 Experiments.
† 80 ditto.
‡ 365 ditto.

Experiments with Steel Rails.

Weight of Rail.	Makers' Name.	20 Tons.		30 Tons.		38·7 Tons.	
		Inches.	Inches.	Inches	Inches.	Inches.	Inches.
68 lbs.	J. Brown and Co.* . .	·32	·15	1·72	1·20	3·87	3·45

*45 Experiments.
Greatest strain rail bore = 50½ tons.

Experiments with Iron Rails.

Weight of Rail.	Makers' Name.	25 Tons.		35 Tons.	
		Inches.	Inches.	Inches.	Inches.
85 lbs.	Patent Shaft Co.* . . .	·64	·51	2·17	1·92
do.	Ebbw Vale Co.† . . .	·56	·40	1·45	1·23
	2)	1·20	·91	3·62	3·15
	Average . . .	·60	·45	1·81	1·57

* 24 Experiments.
† 8 ditto.

Experiments with Steel Rails.

Weight of Rail.	Makers' Name.	25 Tons.		35 Tons.		45 Tons.	
		Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
86 lbs.	J. Brown and Co.*. . .	·26	·10	1·03	·79	3·82	3·45

* 18 Experiments.
Greatest strain rail bore = 64·5 tons.[1]

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[1] A piece of the same rail was experimented on, and 1 square inch area
of the web bore 50·5 tons per square inch tension.
and of the head „ 47·0 „ „ „

Def. of steel rail, with 20 tons : def. of iron rail, with 20 tons	:: 1 : 2		68 lbs. section.
Per. set „ „ „ : per. set „ „ „	:: 1 : 3·3		
Def. „ „ 30 tons : def. „ „ 30 tons	:: 1 : 1·28		
Per. set „ „ „ : per. set „ „ „	:: 1 : 1·72		
Def. of steel rail, with 25 tons : def. of iron rail, with 25 tons	:: 1 : 2·3		86 lbs. section.
Per. set „ „ „ : per. set „ „ „	:: 1 : 4·5		
Def. „ „ 35 tons : def. „ „ 35 tons	:: 1 : 1·7		
Per. set „ „ „ : per. set „ „ „	:: 1 : 1·9		

He thought that no one could fail to be struck with the circumstance of the large proportion of strength there was in the steel rail, when great pressure was not put upon it, though the strain was much larger than anything it would be subjected to in practice. The material was evidently superior, and it would be found to give a better result, under ordinary circumstances of practice, than the ultimate test seemed to indicate.

He had also, in order to satisfy himself on this subject, had pieces cut out of the rail referred to as bearing 64½ tons, and tested, to show what the tensile strength of the metal was. The strength of iron was considered satisfactory, if it bore a tensile strain of 21 or 22 tons on the square inch. A piece cut out of the web of this rail bore 50 tons per square inch tensile strain without breaking. A piece cut out of the top of the same rail bore a load of 47 tons. Other experiments gave the point where elongation was supposed to commence, and the tensile strength of the Bessemer steel of other rails. He must say he thought the strains where elongation commenced were high. The delicacy of the instrument was not sufficient to enable the first movement to be tested. The following were the results:—

TENSILE STRENGTH OF BESSEMER STEEL IN RAILS.

	Elongation commenced.	Broke.
	Tons per sq. inch.	Tons per sq. inch.
Piece taken from web of rail (86 lbs.) (Brown and Co.)	22¼	45½
Piece taken from head of same rail .	26¼	44¾
Piece taken from web of rail (86 lbs.) (Cammell and Co.)	24½	45½
Piece taken from web of rail (86 lbs.) (Cammell and Co.)	22¼	33½
Piece taken from head „	24½	42¾
Pieces from web.—3 experiments. Average breaking weight		41½
Pieces from head.—2 experiments. Average breaking weight		43½

The following table showed the results of some experiments on the tensile strength of Bessemer steel in plates:—

TENSILE STRENGTH OF BESSEMER STEEL IN PLATES.

	Elongation commenced.	Broke.
	Tons per sq. inch.	Tons per sq. inch.
Section = ·625 × 1·55 = ·813 sq. inch	24½	46
Section ·59 × 1·68 = ·96 sq. inch	20¼	43
Section ·54 × ·55 = ·73 sq. inch	20½	44·7
Section ·58 × 1·55 = ·899 sq. inch	22½	44·5

From these tests elongation began at an average of
22 tons per square inch.

The pieces broke at an average of
44½ tons per square inch.

Some plates, tested by Samuda Brothers, broke at = 43½ tons per square inch.

Average of 4 Experiments on steel tried in Holland :
The breaking weight was = 42 tons.

Average of 28 Experiments at Chatham on steel plates for 'Bellerophon :'
Breaking weight = 39·807 tons per square inch.

Average of the whole number (37) of Experiments:
Breaking weight = 42 tons per square inch.

Having thus tested the power of the lower web of the rail to resist tension, it was equally desirable to know what the power to resist compression in the upper web would be. Through the kindness of Sir William Armstrong and partners, he had made some experiments upon the compression of cylinders of Bessemer steel of exactly 0·755 of an inch diameter, which was the only size experimented upon. The result of these experiments was to show, that there was a remarkable uniformity in the point at which permanent set could be discerned. The permanent set was ascertained by means of a delicate instrument, and he thought the perusal of these results would lead to the conclusion, that Bessemer steel of that form, being little more than one inch in height and ¾ of an inch in diameter, would support 18 tons per square inch before there was a permanent set. The cylinders exhibited had been subjected to a pressure of between 50 tons and 60 tons to the inch, and he stopped at that, as there was no object in going further.

EXPERIMENTS WITH STEEL CYLINDERS.

Experiment No. 1.—Diameter ·755.			
Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
5,000	2·232	1·032	
10,000	4·464	1·032	
15,000	6·696	1·032	
18,000	8·035	1·0320	
20,000	8·928	1·0315	·0005
22,500	10·044	1·0285	·0035
25,000	11·16	1·0230	·0090
30,000	13·392	1·0130	·0190
40,000	17·857	0·9750	·0570
50,000	22·321	0·9155	·1165
60,000	26·785	0·8380	·1940

EXPERIMENTS WITH STEEL CYLINDERS—*continued.*

Experiment No. 2.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·033	
5,000	2·232	1·033	
10,000	4·464	1·032	·001
15,000	6·696	1·032	·001
18,000	8·035	1·032	·001
20,000	8·928	1·029	·004
22,500	10·044	1·02	·013
25,000	11·16	1·012	·021
30,000	13·392	·996	·037
40,000	17·857	·944	·089
50,000	22·321	·87	·163
60,000	26·785	·783	·25
80,000	35·714	·572	·461
100,000	44·642	·563	·47

Ultimate diameter 1·09.

Experiment No. 3.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·033	
5,000	2·232	1·033	
10,000	4·464	1·033	
15,000	6·696	1·033	
18,000	8·035	1·032	·001
20,000	8·928	1·032	·001
22,500	10·044	1·03	·003
25,000	11·16	1·02	·013
30,000	13·392	1·01	·023
40,000	17·857	·963	·07
50,000	22·321	·903	·13
60,000	26·785	·82	·213
80,000	35·714	·668	·365
100,000	44·642	·564	·469

Ultimate diameter 1·062.

Experiment No. 4.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·031	
5,000	2·232	1·031	
10,000	4·464	1·031	
15,000	6·696	1·031	
18,000	8·035	1·03	·001
20,000	8·928	1·028	·003
22,500	10·044	1·015	·016
25,000	11·16	1·008	·023
30,000	13·392	·994	·037
40,000	17·857	·95	081
50,000	22·321	·877	·154
60,000	26·785	·79	·241
80,000	35·714	·645	·386
100,000	44·642	·538	·493

Ultimate diameter 1·086.

Experiment No. 5.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·032	
5,000	2·232	1·032	
10,000	4·464	1·032	
15,000	6·696	1·032	
18,000	8·035	1·031	·001
20,000	8·928	1·029	·003
22,500	10·044	1·017	·015
25,000	11·16	1·01	·022
30,000	13·392	·995	·037
40,000	17·857	·953	·079
50,000	22·321	·88	·152
60,000	26·785	·793	·239
80,000	35·714	·65	·352
100,000	44·642	·548	·484

Ultimate diameter 1·077.

EXPERIMENTS WITH STEEL CYLINDERS—*continued.*

Experiment No. 6.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·033	
5,000	2·232	1·033	
10,000	4·464	1·033	
15,000	6·696	1·033	
18,000	8·035	1·033	
20,000	8·928	1·032	·001
22,500	10·044	1·015	·018
25,000	11·16	1·007	·026
30,000	13·392	·991	·042
40,000	17·857	·943	·09
50,000	22·321	·87	·163
60,000	26·785	·775	·258
80,000	35·714	·635	·398
100,000	44·642	·535	·498

Ultimate diameter 1·09.

Experiment No. 7.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·033	
5,000	2·232	1·033	
10,000	4·464	1·033	
15,000	6·696	1·033	
18,000	8·035	1·0325	·0005
20,000	8·928	1·032	·001
22,500	10·044	1·019	·014
25,000	11·16	1·01	·023
30,000	13·392	·998	·035
35,000	15·624	·975	·058
50,000	22·321	·88	·153
60,000	26·785	·803	·23
80,000	35·714	·649	·384
100,000	44·642	·543	·49

Ultimate diameter 1·083.

Experiment No. 8.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·033	
5,000	2·232	1·033	
10,000	4·464	1·033	
15,000	6·696	1·0325	·0005
18,000	8·035	1·031	·002
20,000	8·928	1·03	·003
22,500	10·044	1·018	·015
25,000	11·16	1·012	·021
30,000	13·392	·997	·036
40,000	17·857	·955	·078
50,000	22·321	·888	·145
60,000	26·785	·8	·233
80,000	35·714	·648	·385
100,000	44·642	·546	·487

Ultimate diameter 1·08.

Experiment No. 9.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·033	
5,000	2·232	1·033	
10,000	4·464	1·033	
15,000	6·696	1·033	
18,000	8·035	1·0325	·0005
20,000	8·928	1·032	·003
22,500	10·044	1·018	·015
25,000	11·16	1·013	·02
30,000	13·392	·998	·035
40,000	17·857	·955	·078
50,000	22·321	·886	·147
60,000	26·785	·792	·241
80,000	35·714	·645	·388
100,000	44·642	·573	·46

Ultimate diameter 1·05.

EXPERIMENTS WITH STEEL CYLINDERS—*continued.*

Experiment No. 10.—Diameter ·755.

Weight on		Length.	Compression.
lbs.	Tons.	Inches.	Inches.
..	..	1·033	
5,000	2·232	1·033	
10,000	4·464	1·033	
15,000	6·696	1·033	
18,000	8·035	1·0325	·0005
20,000	8·928	1·032	·001
22,500	10·044	1·021	·012
25,000	11·16	1·012	·021
30,000	13·392	1·	·033
40,000	17·857	·95	·083
50,000	22·321	·896	·137
60,000	26·785	·817	·216
80,000	35·714	·667	·366
100,000	44·642	·562	·471

Ultimate diameter 1·06.

He would mention a further experiment which was made upon axles. Having heard that some cast-steel axles were being tested in an extraordinary manner, he thought he would try Bessemer steel axles by the same test, not supposing they would stand so extraordinary a force. The axles were 3¾ inches diameter in the middle and 7 feet 2 inches long, and were placed on bearings 3 feet apart. He subjected them to a series of blows from a 15 cwt. ball, falling through 5, 10, 15, 20, and 35 feet.

EXPERIMENTAL TESTS OF BESSEMER STEEL AXLES, AT THE ATLAS STEEL AND IRON WORKS, SHEFFIELD, JANUARY 9TH, 1866.

Carriage Axles.

The axle to be tested was placed upon bearings 3 feet apart; the falling 'tup' weighed 14 cwt. 3 qrs.

Experiment No. 1.

First	blow,	fall	5	feet,	bent the	axle	1⅞	inches.	
Second	„	„	10	„	„	„	3¼	„	total 5⅛ inches.
Third	„	„	15	„	„	„	5¼	„	„ 10⅜ „
Fourth	„	„	20	„	„	„	6⅝	„	„ 17 „
Fifth	„	„	35	„	„	„	8⅛	„	„ 25⅛ „

This axle could not be bent any further by a falling weight; there was not the least sign of any fracture.

Experiment No. 2.

First blow, fall 10 feet, bent the axle 4½ inches. This axle was then turned over, and the

Second blow, fall 15 feet, bent the axle to 1¾ inches beyond straight. The axle was then nicked in the centre with a cold chisel for the purpose of breaking it; and the

Third blow, fall 35 feet, broke the axle and caused the ends to ascend a considerable height, one part falling 55 feet away from where it was struck by the tup.

EXPERIMENTS AT THE CYCLOPS STEEL WORKS, SHEFFIELD, JANUARY 31ST, 1866.

Experiment No. 1.

Weight of tup 14 cwt., axle placed on bearings 3 feet apart.

First	blow,	fall	11 feet 6 inches,	bent the axle	5¼	inches.		
Second	„	„	17 feet,	„ „	6⅞	„	total	12⅛ inches.
Third	„	„	23 feet 6 inches,	„ „	8⅜	„	„	20½ „
Fourth	„	„	36 feet, broke the axle.					

Experiment No. 2.

First blow, fall 30 feet, bent the axle 12¾ inches, when it was turned over, and a Second blow, fall 30 feet, broke it.

Experiment No. 3.

First	blow,	fall	5 feet	3 inches,	bent the axle	2	inches.		
Second	„	„	10 „	6 „	„ „	5	„	total	7 inches.
Third	„	„	15 „	9 „	„ „	6½	„	„	13½ „
Fourth	„	„	21 „		„ „	6¾	„	„	20¼ „
Fifth	„	„	30 „		„ „	6¾	„	„	27 „

No sign whatever of any fracture.

Experiment No. 4.

First blow, fall 10 feet 6 inches, bent the axle 4½ inches.

Second blow, axle turned over, fall 10 feet 6 inches, brought the axle back straight. It was afterwards nicked with a cold chisel, and a blow, with a fall of 25 feet, broke it into three pieces, one piece coming out of the middle.

It would be readily imagined that only good metal could have supported such a test.

As to uniformity, if a good article either in iron or steel was wanted, undoubtedly there must be a good material to start with, and the conversion must be made with proper judgment. Granting that, then there seemed a doubt on many minds, whether this material, so made, would be of uniform strength. It would not be perfectly uniform, neither would iron or any other metal be so in practice. Some boiler plates of iron, supplied by a firm of eminence, which he recently tested, would not bear a strain of more than 16 tons to the inch, and he rejected them. He had tested boiler-plates with 26 tons to the inch; therefore, uniformity did not seem to exist in iron. When there was a difference of 35 or 40 per cent. in the iron sent out by the best manufacturers, he did not think that uniformity could be looked for in Bessemer steel, or in any other material. But the experiments, as far as they went, showed that as much uniformity might be relied upon in that material as in others.

He had given the best information he had on this subject, but it was not that which the Members ought to be satisfied with. These facts, together with those which had been brought forward in the Paper, only showed the necessity of getting together a larger number of similar facts, and from that larger number to arrive at some approximation to the truth. With this view, he suggested that a series of experiments should be organized by the Council of the Institution, and should be carried out on such a correct and comprehensive scale, that they should command something like authority. By that means he thought great good might be done, and that the introduction of Bessemer steel into the structures of art of this country might be shown to be advantageous. He begged to place his services entirely at the disposal of the Institution for that object.

Mr. FRANCIS FOX fully endorsed all that had been said with regard to the value of the great mass of statistics that had been brought forward; at the same time he confessed, as an Engineer having charge of the permanent way of a railway, he felt a little disappointed in the Paper. The subject was no doubt a vast one, and he had hoped to hear a great deal about everything connected with the maintenance and renewal of the permanent way of railways. He had heard some valuable statistics, but they seemed to resolve themselves, almost entirely, into the question of the relative merits of steel and iron rails. Following up the remarks of Mr. Berkley, he would express a hope that such an inquiry would be carried out, not only with reference to the question of rails, but that it would be extended to those numerous other items which entered into the cost of the maintenance and renewals of a railway, and which he need not here enumerate. The Author had included in the statistics 'reconstruction' of works; for although the Paper was entitled "On the Maintenance and Renewal of the Permanent Way of Railways," the works and other items forming portions of what was ordinarily called the 'line account,' were given; that was to say, the whole expense of the maintenance of the structure of a railway. Mr. Fox would also have been glad, if there had been some statistics bearing on the whole question of the cost of the permanent way, and not confined to that of the wear of the rails only.

He did not know how these statistics had been arrived at, but all must agree, that the published reports of Railway Companies were not the most satisfactory sources for ascertaining the cost of the maintenance of railways, because there were so many different ways of stating things. Some companies charged renewals to a renewal fund, and he, like other Engineers who had charge of a railway, naturally turned to the 'line account,' and he was often astonished to find that a certain company appeared to maintain its permanent way on a very economical scale; but on turning to another part of the account, he probably found a 'renewal of rails' account, which stood debited with a large amount under that head. He had no doubt the Author had taken these things into consideration; but he should like to see detailed returns from every railway company, giving those statistics in a reliable form, both as to maintenance and renewals. Some persons called maintenance little more than packing, and jointing, and fencing, whilst others carried it much further; there seemed to be a great want of definition in points of that kind.

The most valuable part of the Paper appeared to him to be, that which gave a certain relation between the tonnage carried and the life of a rail; if the data were extended to other points also, he thought they would be extremely valuable.

With regard to the question of steel rails, he had prepared for his own guidance a statement as to the relative cost of steel and iron rails. It struck him there were two or three methods of estimating the value of steel as against iron rails; and he need not say, as the question was entirely an economical one, it was all-important on what principle the comparison was drawn. Take, for instance, 100 tons of steel rails at £16 per ton—viz., £15. 10*s*. per ton, cost price, and 10*s*. per ton for laying—lasting any given number of years, and bringing back £8 per ton when worn out; then take a like amount of iron rails at £7. 10*s*. per ton, and 10*s*. for laying, making £8 per ton. One method of estimating the annual cost would be to take the first outlay of £1,600, and to add the simple interest of that sum for the number of years' duration of the steel rails; to set against it as a credit the sum brought back by the old materials, and then divide the sum by the number of years' duration. That was a plan which appeared at first sight to be a correct one; but he was not at all sure it was so; and the more correct plan, perhaps, would be to carry on the operation for a series of years. He had calculated, as a matter of curiosity, on a term of a hundred years, and he had found some strange results to arise. It appeared that the cost in that case was a progressive one; and that instead of the average cost of iron rails lasting three years, being £173 or £174 per annum when reckoned for a term of three years only, it came to no less a sum than £493 per annum, when calculated for a series of ninety-nine years. Another mode of calculation, which he believed was in use with some Engineers, was to reckon what sum placed at compound interest would represent a given sum, available for renewals at the expiration of a given term of years. He thought, however, that that was not a correct mode of calculation, because the money was expended at the outset in the purchase of the rails, and it was therefore running at interest during the whole time of their duration. Moreover, he did not believe that compound interest ought to enter into the question; for if an Engineer, by the use of steel rails, saved £1,000 or £10,000 in any half year, the sum so economised went into the pockets of the shareholders as dividend, and was therefore not itself accumulating interest. This consideration was at the root of the whole question, viz., what would steel rails, as against iron rails, save in any given number of years? Taking the case of the 100 tons of steel rails at £16 per ton, even if they lasted for ever, they would cost £80 annually for interest. It could therefore be conceived that iron rails, lasting but a few years, might be quite as economical as steel rails lasting for ever. The table he had drawn out was based on the supposition of different periods of duration, and it enabled him to form a comparison between iron rails lasting a certain number of years and steel rails lasting a certain longer period of years. He should be obliged if the Author, before the close of the discussion, would state the principle of calculation on which his comparison of the cost of steel and iron rails was based. He would say, as an Engineer having chiefly to do with bridge rails, that he found considerable discrepancy between the results of the tests given by Mr. Kirkaldy and those contained in the Paper which he had presented to the Institution some years ago. He could not account for this discrepancy, because several experiments were tried by him with generally uniform results; at the same time it was not fair to test a bridge rail, supported at every point, in the same way as a double-headed rail, with only partial bearings on the chairs. By referring to the table attached to his Paper, it would be seen what was the strength of the bridge rail placed on longitudinal timbers, and it would be found that the two together formed an exceedingly strong system of girder. With regard to the use of steel rails, there was no question they would last out a number of iron rails. He had put steel rails down in situations where they showed scarcely any wear, and where iron rails were worn out in a few months. In such cases there could be no question whatever as to the advantage of using steel rails; but he thought there was a point at which it was more economical to use iron rails, looking at the difference in price. At the same time, steel rails were undoubtedly good for crossings and switches, which were subjected to a good deal of wear, and in such cases he used scarcely anything but steel.

Iron permanent way had been characterized by the Author as a failure; and in support of that view, Mr. W. H. Barlow's general condemnation of the Barlow rail had been quoted.[1] Now Mr. Fox did not agree in that opinion, because he did not think the system had had a fair trial; and he believed that if a better material had been used, and it had been differently jointed, that was, if instead of being firmly riveted together it had been jointed in a manner to allow of expansion and contraction, it would not have been condemned so strongly as it had been. Referring to another system of iron permanent way, of which 14 miles were laid upon the Bristol and Exeter Railway, a portion of it in 1853, he might state that there was no apparent deterioration of the base on which the rails rested, and he regarded that fact as proving his opinion, that if the base lasted so long, there must be some advantage in using iron as a base instead of timber, which under ordinary circumstances lasted only a comparatively short time. However, he did not advocate iron as a substitute for timber in all cases for the permanent way of railways. He might, however, state, for the information of the Institution, that a piece of iron permanent way which he laid in 1861, and which consisted of a bridge rail, laid upon a longitudinal T iron base 12 inches wide, with a rib projecting 3½ inches from the centre downwards, with a cushion of wood between the rail and the iron base, had proved the best system of iron permanent way that he had adopted. There were however certain defects belonging to any iron way; as for example, it required better ballast, and probably a little more labour in packing; the nuts were liable to give trouble by working loose, and it was more costly in the first instance. He had also tried the system known as De Bergue's iron way, and it succeeded better than he expected it would do. The breakage of chairs was only about one half per cent. per annum of the total number laid. It took a little more labour in packing, but made a very fair road; and with some improvements in the arrangement of the cross transoms, it might be made a good road. It was not more expensive in first cost than a timber road, and there was a saving of nearly the whole cost of the renewal of timber.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xx., p. 259.

He trusted that this valuable Paper was only the commencement of a series of Papers which would enter into the whole subject, so important to the railway world, inasmuch as the aggregate cost of the maintenance and renewals of railways in the United Kingdom might be estimated at many millions sterling per annum, and anything that could tend to lessen this enormous cost must be of extreme value. He had always been an advocate for the longitudinal system of permanent way, and he found nothing in the accounts of other companies to lead him to think, that the longitudinal system of way was more expensive to maintain than the transverse system. He was, no doubt, in the minority amongst Engineers on that point; he was, however, open to conviction, and in conformity with the suggestion of the President, he should be happy to contribute towards the supply of any information bearing on this important and interesting question.

Mr. VIGNOLES said, allusion had been made to the difficulty of comparing the expenses of maintenance on different railways; and he thought there was nothing in which the Institution could do greater service, to the public and to railway companies, than in pressing upon the Government the importance of getting statistics in regard to railways as well as in other departments. In Germany the collection of statistics was most perfect, and there the minutest difference of cost upon the several lines could be traced. With respect to difference in the weight of metal, the Bessemer rail might undoubtedly be lighter than those now in use, and therefore credit should be given for the weight of chairs (where abandoned) to be added to the weight of the present very heavy rails, should the Bessemer rail be adopted.

Mr. ROCHUSSEN would endeavour to contribute a short chapter to the history of the life of rails, by the exhibition of two compound steel rails of early manufacture. He had tried to ascertain whether rails of that description had been made prior to the year 1854, but he had not been able to find any. These rails were laid at the Hamm Station of the Cologne and Minden Railway in February 1854. The line at this point was perfectly level, and the soil was loam. The rails were supported by oak sleepers 8 feet long, and 11 inches wide, by 6 inches thick, laid 3 feet apart, and the joints of the rails were supported, not suspended, and the elasticity of the line was increased by a bed of gravel 13 inches thick, under each sleeper. The iron rails at the Hamm Junction were found to have a life of barely two years; and a desire having been expressed to find a more durable material, the managers of the works with which he was connected, were consulted, as to whether steel could not be applied to the head of the flange rail, which was done with complete success. After having been laid eleven years, only one side of the head was slightly worn, and the other side was not touched. He was not able to state the exact weight of the traffic which passed over those rails, inasmuch as the Cologne and Minden, like most Prussian lines, only took account of the actual traffic of loaded carriages and trucks, not including the weight of the rolling stock or the running of empty carriages and wagons. The actual nett weight of traffic carried on the Berlin and Cologne portion of the line was stated to be about 12½ million tons: adding to that the weight of the trains, it would represent about 17½ million tons. They had besides a traffic from other lines, which had running powers over this railway, from north-west to south-east, and then again to the north, which might be estimated, independently of the empty carriages, at 30 million tons. These rails were 56 lbs. to the yard, and the steel used in the manufacture was only a thin slab of puddled steel of about ⅜ths of an inch; the steel portion forming only about 12½ per cent. of the whole section. The advantage of this combination he considered to be a degree of elasticity, where it was most required; the iron to resist the great strain through oscillation, and the steel to give greater durability to the head; and thus the rail, while more durable in itself, was less injurious to the axles and springs which ran upon it. It was, however, found, after some experience with this section of rail when combined with cast steel, that a mere facing of cast steel on the iron was not durable, and that to produce a complete combination of cast steel and iron, without desintegration by the vibration of the rail, it was necessary to have as a minimum 47½ per cent. of the section of steel. In comparing this manufacture with Bessemer cast steel, it might be asked why puddled steel had not been wholly used for the web and bottom of the rails. To this he would answer, that it was desired to have a certain amount of elasticity somewhere; and therefore in the new construction, iron was put in the bottom, although it properly belonged to the web. It could not at present be settled what these rails would do as compared with puddled steel, but they promised good results. A great deal depended upon the material itself. The name of Bessemer stood so high, that it would always be a landmark in the annals of iron manufacture. But that which bore the name of Bessemer metal was not always entitled to the hall mark of that good name. Unless good iron were used in the first instance, they could not have good steel; and he urged Engineers not to yield indiscriminately to the Bessemer metal, as it all depended upon the quality of the material employed.

Mr. Siemens had pointed out what could be done with the old Bessemer rails, viz., melted as scrap; but Mr. Rochussen might state there was a far better application than that—viz., simply to cut up the iron rails into proper lengths, roll them into billets and rods, and then draw them into telegraph wire. They could do this with good Bessemer steel up to No. 8 gauge wire; and as fencing and telegraph wire it was capable of very extensive application.

Mr. G. W. HEMANS said, as this discussion seemed likely to merge entirely into the question of the manufacture of rails, which should stand any amount of wear and tear, he was anxious, before it fell altogether into that groove, to arrest the attention of the meeting for a moment on the engineering principles which were to be regarded in the putting together of the permanent way, which he thought were distinct from the question of the particular manufacture of the rails. The Paper embodied a large amount of experience, collected from various sources, for which they were much indebted to the Author. There was one point with which he entirely agreed, viz., that the ingenuity applied to the engineering details of the permanent way had by no means kept pace with railway improvements in other matters—as in engines and rolling stock, the construction of bridges, &c.; but on the subject of the construction of the permanent way it had remained almost stationary, as, with the exception of the marked improvement of the fish joint, the permanent way at the present day was really almost what it was twenty years ago. It might appear presumptuous to bring forward his own experience in these matters on the few hundred miles he had constructed in Ireland and elsewhere, against the thousands of miles that had been constructed by more eminent men, still he ventured to think there was room for great improvement in the prevailing system of permanent way.

He would direct attention to the abstract principle of construction of the permanent way as it now for the most part existed. It appeared to him, that the ordinary permanent way, with cast-iron chairs, really consisted of a series of iron bars laid upon iron anvils, tightened up with wooden keys more or less loose, and with very small bearing surface. There must arise from that a great vibration and wear and tear of material; and his impression was, that a great deal of it arose from defective construction in this mode of putting together the permanent way. Under a heavy engine, there was a deflection of the rail between every chair on which the rail rested; and there was no doubt when the rails were turned, as they sometimes were, and which he thought was not a judicious operation, at every chair, where the bearing did not exceed 2½ inches on the seat, an indentation had occurred to something like ⅛th of an inch in the bottom seat of the rail. That could not arise without injury to the whole structure of the rail; and he thought it time that something was done to improve that construction. The cost of the ordinary form of permanent way, in which the rails were fixed with wooden keys into cast-iron chairs, compared with fixing the rails without cast-iron chairs, direct upon cross sleepers, was about £374 per mile in excess; that was, the chairs cost between £300 and £400 per mile. By that plan it was said the rails might be turned; but he thought that was not desirable. Many attempts had been made to do away with this system of permanent way. Mr. Brunel adopted the bridge rail laid upon longitudinal timbers. That system had not met with favour, partly, perhaps, because it was said that the drainage was not so good, and that longitudinal timbers decayed a little faster than cross-sleepers; but the great evil with the bridge rail, and he believed the reason it had failed, was, that it was impossible with that section to make a good joint. There was no mechanical contrivance which could be introduced to prevent the ends of the rails being driven into the timber when upon a flat plate, as efficiently as the ends of a double headed rail could be fished and supported. He believed that was one of the reasons why the bridge rail upon longitudinal timbers had fallen into disfavour.

He would mention a fact with regard to the durability of rails which had surprised him. Eighteen years ago, on the Midland Great Western Railway of Ireland, he laid about 30 miles of the

Vignoles rail, not, as was generally the practice, upon cross sleepers, but on longitudinal bearings. Last year the rails on the other portions of the line got into disrepair, and he was called upon to report on the subject. To his surprise he found the flat-footed rails, on longitudinal bearings, still in use and in good condition, and likely to last a few years longer. The only evil was, that the ends of the plates, on which the rails rested, had been indented into the timber and become loose, simply because fishing the joints had not been then discovered, and for that reason they were not so successful as they would otherwise have been. That experience was sufficient to show, that rails, properly laid, on longitudinal bearings, without the intervention of chairs, caused the pressure of the heavy locomotive to be transferred through the rail directly upon the ballast, and that that system of bearing would better sustain the heavy rolling weights now used, than the iron supports at short intervals with small bearings, and with the deflections which caused so much disturbance to the rail. He therefore believed that the flat-footed rail, sufficiently deep to allow of good fishing, though it was entirely out of fashion and forgotten in the present day, ought to be revived; and if the longitudinal bearings were of timber, well chosen, and well creosoted, whether the rails were of iron or steel, that would be a mode of construction best calculated to resist the enormous weights of rolling stock now used. At least 70 per cent. of the rails referred to as having been laid for eighteen years were still in good condition. Being a main line the traffic was considerable, though not equal to any of the great English lines, nor to be compared in point of weight of goods conveyed. Rails laid in the same situation, upon cast-iron chairs, would have been worn out seven or eight years ago. The traffic probably would not exceed thirty trains per day, including goods and cattle and all specials, in both directions.

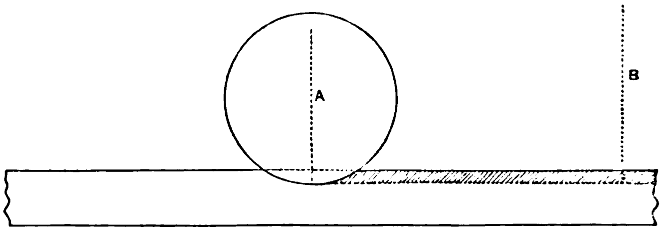
Mr. G. H. PHIPPS wished to mention, as a matter of history in connection with the competition offered in 1834 by the Directors of the London and Birmingham Railway Company for the best form of rail for that line, that he, in conjunction with Mr. Birkenshaw, sent in a design for a rail with a fish joint complete, as shown in the original wooden model which he now exhibited.

With regard to the immediate subject of the Paper, the Author had addressed himself more to the consideration of the rail alone than to the other component parts of the permanent way, probably because the rail was the only part of the permanent way on which the Author saw his way to improvement. The Author had gone largely into the merits of steel rails, and in the commendation which had been passed upon them, Mr. Phipps entirely concurred, and considered it amply supported by the experience with the steel rails laid at Chalk Farm. Having read carefully the observations in the Paper, corroborating the Author's views, by Mr. Johnson, and with the data given as to the price and duration of the rails, he quite concurred in the statement, that there would be a saving effected of 50 per cent. of the cost of iron rails. Having admitted that much, with regard to the excellency of steel rails, it was clear that it would be desirable to use them on lines with a large amount of traffic; but, prior to using steel rails on a large scale, he thought it desirable to determine, whether the amount of adhesion of the locomotive wheels with steel tires upon steel rails would be the same as between steel tires and iron rails, for that perhaps admitted of some question. He had hardly formed an opinion on it himself, but he thought it would not be prudent to use steel rails largely without determining that point.

With regard to the destructive effects of high speed upon the rails, from the information given by Mr. Meek, it appeared that with the same locomotive engines, and everything similar except variations of speed, the same rails required more than three times the traffic to wear them out at the lower speeds. There was no statement given of what the comparative speeds were; but he believed it would come out that, for equal quantities of traffic, the wear of the rails would be in the ratio—not of the velocity simply, but of the square of the velocity; a proposition which he thought would be found equally amenable to practice as to reasoning.

Assuming Fig. 1 to represent a railway wheel and rail, with a given weight upon the wheel, it would bed itself by actual compression a certain distance (shown by the etched lines) into the substance of the rail. All the matter shown by the etched lines would then have to be displaced by the wheel during the time of its passage from A to B (just as the water in its path was displaced by a vessel), and in proportion to the shortness of the time of passage would be the speed of displacement, the resistance being, therefore, as the square of the speed. Whilst upon the subject of the destructive effects of speed, he would refer to a letter, addressed some years ago, by Mr. G. R. Stephenson, to the President of the

Fig. 1.



Board of Trade,[1] as to the desirability of slow speeds upon railways for conveying mineral traffic. It was shown in that letter, that if the mineral traffic were separated from the passenger traffic, and a slower speed adopted for the former, it could be carried with much less destruction to the rails and rolling stock, and therefore with more economy. If the destruction was as the square of the velocity, and the line of railway abounded with inclined planes up-hill and down-hill, with a diminished speed up-hill and an increased speed down-hill, the wear and tear would be considerably greater, than if the same space were traversed at an uniform speed equal to the average speed.

The coal traffic on the Great Northern Railway, and its destructive effects upon the permanent way, having been particularized in the Paper, Mr. Phipps could not forbear from referring to the economy which would have been effected, in the conveyance of coal to the east end of the metropolis, had a line laid out specially for that purpose a few sessions ago fortunately received the sanction of Parliament. He had been much struck with the fact stated in the Paper, of the far greater destruction of the rails on the down-hill inclines of the Great Northern, over those on the up-hill inclines with an equal amount of traffic; for he confessed that, if he had been asked whether there would have been more destruction to the rails on the up-hill inclines, subjected as they were to the full tractive power of the wheels of the engine, or when going down-hill with less tractive force, he would have expected the wear and tear to have been greater upon the up-hill inclines; the contrary effect, however, simply showed the enormous percussive effects due to speed in destroying the rails.

With regard to the observations made by Mr. Vignoles, upon the importance of using rails without chairs, and also what had fallen from Mr. Hemans, advocating the same kind of rail, it occurred to him—first, that in order to make a rail of this kind equally stiff with the ordinary double-headed rail, it must be equally deep; and if that were so, with the long slender stalk presented by such a rail, he thought it not so well adapted to meet the lateral strain arising from heavy locomotives, as the double-headed rail, which was supported more directly against lateral force by the ordinary railway chair.

Mr. BESSEMER said, an important question had been raised, with reference to what was to be done with the old steel rails. The question was one of great importance, when they considered the first cost of steel rails. It had been partly answered by Mr. Siemens, who said that a ton of old steel rails could be melted in his furnaces with a ton of small coal. But it had been found that, with 8 cwt. of coke a ton of old steel rails could be melted in a cupola, and be carbonized to such a degree, as to make them run from the furnace in the condition of white pig iron, and by a subsequent operation be remanufactured into the Bessemer metal. Another way was to put into the converting vessel one ton of old rails, and with the excessive temperature there generated, they would be melted and form part of the new charge of steel. But each of these plans had serious disadvantages, inasmuch as the new portion of metal so obtained was only in its first stage of manufacture, while the metal of the old rails had already passed through every stage. The rail itself had undergone all the operations of hammering, rolling, cropping, and the cost also of several heatings and wear and tear of furnace, and at last was brought into the condition of wrought steel. It was not wise, therefore, to convert such wrought metal again into the unwrought or ingot state. Hence he found that the most advantageous mode of working up old rails was to roll them into plates or bars of another section. An example of what could be made from the crop end of a rail was exhibited, in the shape of a sheet of steel 9 feet long by 1 foot wide. That was metal cropped from the ordinary end of a steel rail, and passed through the rollers; if the crop end had been put in crossways between the rolls, it would have been increased in width, and formed a sheet 6 feet long by about 3 feet wide. Hundreds of tons of these sheets were now manufactured in Sheffield, in great variety of size and thickness, the crop ends of the rails being sold for this purpose at £7 10s. to £8 per ton, notwithstanding the imperfect state of a portion of each crop end.

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[1] *Vide* "High Speeds." A Letter to the Right Hon. T. M. Gibson, M.P. By G. R. Stephenson. 8vo. (Tract, vol. cxxvii.) London, 1861.

To revert again to the old rails: a yard of the old rail from the Chalk Farm station had been rolled into small round rods at Sheffield, with a loss of not more than 2 or 3 per cent. in weight. These rods, several of which were exhibited, could be used for many purposes. Having incurred an expense of £2 to £3 per ton for the rolling, they would be worth £18 per ton at the present market price; and in that way the old rails became in fact more valuable than new ones. At all events, ordinary tin-plate bars of charcoal iron, of the same sectional area and form as a rail, when passed through plain and flat rolls, were worth £13 per ton; and this metal, which was much better in quality for rolling into tin plates, would be worth at least £12 per ton, after the rail had worn out seven or eight ordinary iron rails.

New railway bars in steel had generally been compared with iron ones of the same weight, and 84-lb. double-headed rails appeared to be the favourite type of rail for that purpose. Perhaps at first it was better to keep to the same scantling, merely replacing the iron with steel; but now that the great durability of the steel rail had been proved, it behoved those who regretted its first cost, to ascertain how far the first cost of the rails could be reduced by diminishing the weight, rather than by unduly diminishing the profits of the manufacturer. Mr. Kirkaldy's experiments showed that, as a beam supported on bearings 5 feet apart, the ordinary 84 lb. iron rail sustained a weight of 5 tons to the square inch of cross section, while the steel rail stood 10 tons to the square inch under like conditions. As the bearing surface of the rail need not be decreased in proportion as the general structure was decreased, it became necessary to ascertain what weight of steel per yard represented the same bearing power as the iron rail and the same resistance to cross strains as a given weight of ordinary iron rail. Taking, then, the fact that the tensile strength of the steel rail was nearly double that of the ordinary rail, these experiments, as far as they went, showed, he thought, that the weight of the steel rail might with safety be reduced by one-third. He believed a steel rail of 56 lbs. per yard, instead of 84 lbs., would bear a heavier strain than an ordinary iron rail of the latter weight, without either deflection or permanent set. Assuming, then, the price of steel rails to be £14 10*s*. per ton, and ordinary iron rails £7 10*s*. per ton, taking off one-third of the weight would bring the steel rails within about 43*s*. per ton of the cost of ordinary rails, and the old steel rails would be worth at least £10 per ton when done with. The necessary weight of steel rails was a point which should undergo strict investigation. Nor was that all. The first cost of the rail was not the only thing to be calculated. The rails had to be carried to their destination, and the old rails had to be taken away; then there was the turning of the rails as they became worn; indeed the labour consequent on the cost of the frequent renewals of the iron rails was far more than equivalent to the first cost of steel. The injury to the rolling stock must also be greater where the rails gave way at certain parts. The frequent concussions from that cause must assist in wearing out the wheel-tires, and at the same time do much injury to the rolling stock. These matters were important in an economical point of view. Then, again, the iron rails were a source of danger to the traffic of a line, from the number of times they had to be lifted. All parts of the line had to be lifted at some time or other, and when that was done, between the intervals of passing trains, it was a great source of danger; and he thought this point also required further investigation. In a matter of this kind it could hardly be expected that everybody would be of the same opinion, as there were old notions which it was difficult to overcome. When steam navigation had been proved to be a success on rivers, Dr. Lardner regarded the difficulties of ocean steam navigation as almost insurmountable. He quite admitted that, before a line of railway was laid with steel rails throughout, further proof was required, to enable the proper form and weight of a steel rail to be determined, and that point could best be effected by the members of the Institution. Just previous to the introduction of this Paper, he had proposed to undertake a series of experiments, to determine what strains ordinary Bessemer steel would sustain in practice. No one thing was more wanted than that. A good deal had been said about tensile strength, but very little about compressive strength. Mr. Bessemer would like to undertake a series of elementary experiments, in the first instance, so as to give means to establish correct formulæ, and then to construct some girders of a size to set the question at rest for ever. He should be happy to have the assistance of the Council of the Institution in this matter, because he wished the results to be made known for public information; and if the Institution, through some of its members, would witness those experiments, and verify the facts as proved, it would afford valuable information, which at the present time was much wanted.

Mr. HAWKSHAW, Past-President, said, he quite concurred in one observation in the Paper, that as much progress had not been made in the improvement of the permanent way, as in other matters connected with railways. That had not arisen, in his opinion, so much from the want of knowledge of what was necessary to make a good permanent way as from notions of false economy. As he had remarked on a previous occasion, when similar questions had been raised, it was impossible to decide between different plans of permanent way, by statements of what had arisen on particular lines, unless informed of all the circumstances of each case. Take, for instance, the observations with regard to the Midland Great Western Railway of Ireland, when it was pointed out that a rail of a certain form, and a permanent way of a certain description, after eighteen years' wear, were still in tolerable condition. But he could point to rails of another form—double-headed, for instance, with cast-iron chairs—which, after as great or a greater lapse of time, were in an equally good condition. In fact, statements to the effect that the rails on some railways had lasted eighteen years, without any information as to the number of wheels that had run over those rails, and other necessary facts, led to no useful results whatever. He had laid double-headed rails over which trains had been running for twenty years, and he had laid similar rails, where the traffic was much larger, which had been worn out in half the time; therefore unless the number of vehicles which passed over the rails was stated, no useful conclusion could be arrived at. He agreed that the double-headed rail was subject to deflection; but so at present was every other kind of permanent way. If the rail was laid on longitudinal bearings it deflected. This could only be remedied by greatly strengthening the rails, greatly strengthening the sleepers, and by greatly improving and increasing the ballast; in proportion as this was done would the deflection be diminished.

The first railway he was connected with—the Manchester and Bolton Railway—was laid with the flat-bottomed rail on longitudinal timbers about the year 1834, and for the last twenty years, or more, he had been using that rail, as well as double-headed rails. In Russia, in particular, he had used the flat-bottomed rail on longitudinal timbers, because it made a cheap permanent way, and was sufficient for traffic at moderate speed. He believed that as perfect a road could be made with double-headed rails, cast-iron chairs, and cross sleepers, as with any other description of rails; but he admitted that there were other questions to be considered. In fact, as regarded the weight of the rails, scarcely any advance had been made. For the last twenty years Engineers had used rails of 75 lbs. to the yard, though locomotives had in that time been greatly increased in weight. There had been little change, with the exception that the sleepers had been laid a little closer, and the fish-joint had been introduced. He believed the first desideratum was to add to the weight. If it was wished to run at high speeds with locomotives of double the weight, it was plain that the weight of the materials which had to resist impact must be increased. The rails, sleepers, and ballast were nearly the same as they were twenty years ago.

With regard to steel rails, he thought their use was only a question of time, and that they would be adopted as steel tires had been. It was a better material; the difference in cost was not very great, and he thought Mr. Bessemer was wrong in suggesting, as an inducement to use steel rails, that their weight should be reduced. Mr. Hawkshaw recommended that the weight of the steel rail should not be less than 70 lbs. or 80 lbs. per yard. If reduced to 50 lbs. or 55 lbs. per yard, with locomotives weighing 30 tons or 35 tons, running at 40 miles or 50 miles an hour, steel rails would be a failure. Therefore, those who were considering whether to use steel rails had better adopt the proper weight, because weight was an important feature, and it was that in which they had failed. He was already using steel rails to a limited extent, and he hoped to do so with success. He would express his thanks for this able Paper, which did the Author the greatest credit, and was, on this particular subject perhaps the best that had ever been brought before the Institution.

Mr. RICHARD JOHNSON felt, as the railway with which he was connected had been mentioned in a prominent manner in the Paper, it might not be improper in him to say a few words. He could confirm the statements in the Paper with reference to the durability of the rails on the Great Northern line, and he might say, that for the last five years he had been more or less considering the advisability of recommending to his Directors the use of steel rails. At the present moment they had in use, in round numbers, about 2,000 tons; namely, through the Peterborough station for 2 miles, which had been in work about eighteen months; also through the Doncaster station, and about 500 tons at the London end of the line. He had been engaged during the last few weeks in preparing a calculation (Vide Appendix to the Paper, Table 14) to show at what point it became economical to use steel rails,—for that seemed to be the object which they wanted to arrive at; and he found, taking steel rails at £14 per ton, they were cheaper year by year, considering the period of twenty years' duration, than guaranteed iron rails at £9, with a wear of eight years. When he said guaranteed, it had for some time past been the custom of the Great Northern Company to buy rails with a guarantee; the traffic being heavy, the Directors thought it wise to ask for a guarantee from the makers; and for the last five years they had had a five or a seven years' guarantee with most of their rails.

The calculations he had prepared went to show, that steel rails at £14 per ton were cheaper year by year, as before stated, than iron rails at £9 per ton. They were cheaper in the first instance, he might say. Dealing with a single mile of rails, he found, after adding interest on the outlay, that the cost of a single mile of steel rails for the first year was £148 19*s.* 6*d.* as compared with £152 17*s.* 1*d.*, the cost of iron rails guaranteed for seven years, and supposed to wear eight years; and, similarly, that throughout the whole of the period of twenty years, the outlay for steel rails would be much less than for iron. But there was a further view of this subject, to which, owing to its great importance, he was anxious to direct attention. Taking the main line of the Great Northern railway from London to Doncaster, the Leeds, Bradford and Halifax, the West Yorkshire, and the West Riding divisions, also the Nottingham line,—all of which the Company now maintained,—they had something like 243 miles of double line, or 486 miles of single line. Taking the life of an iron rail at eight years (by supposing it to live one year beyond the seven years' guarantee), he found that about 61 miles of single line would have to be relaid every year; that was to say, the whole 486 miles of single line in eight years; and the cost of that, if iron rails were used, would be £85,400 per annum. Now came the question, how would the account be affected if steel rails were adopted? It came out, that for steel rails at £14 per ton, the expenditure would be £110,837 per annum for the eight years, till every part of the line had been relaid with steel rails. The result was, that during those eight years the steel rails would exceed the cost of iron rails, (reckoning interest on the outlay) by £255,046; but, having relaid the whole with steel, a period was then arrived at when he presumed there would be a little rest. For the next twelve years, he repeated, there would be a state of comparative rest; but then this, what he might call debt, of £255,000 would have to be paid; and he found, that in addition to the paying off of this debt, the question of re-sleepering the steel rails would have to be considered. The sleepers would last about ten years. He calculated that for re-sleepering each portion of the 486 miles at the end of about ten years, the yearly cost would be £21,020. Now, at the end of eight years there was a debt of £255,000; to pay off which it would be necessary to expend something like £27,240 per year; but in addition there would be the further sum of £21,020 a year for re-sleepering, making an annual outlay for twelve years of £48,460. It would easily be seen, that during this period the advantage of having used steel rails was becoming apparent, for had iron been employed the outlay would have been £85,400 a year; therefore, when once the period of eight years was passed, there was a difference in favour of steel over the whole line of something like £36,940 per annum. These figures had astonished him. Taking into consideration all the expenses, he had charged the steel rails with £519 per mile for re-sleepering, allowing for a proper proportion of broken chairs, keys, and the like. The result was, that there was a balance, after the eighth year, in favour of steel, of £36,940; on which annual excess, for the purposes of comparison, interest also should, of course, be reckoned. With regard to his own experience in the maintenance of various kinds of permanent way, he was in favour of the double-headed section of rail. There were on the Great Northern many miles of flat-bottomed rails on longitudinal sleepers, but after being in work for twelve years they required to be relaid. The rails of the double-headed section on the Loop line, 72 miles in length, which was opened in 1848, were 72 lbs. to the yard; these rails had been in use eighteen years, and, with the exception of the renewal of 4 miles, they were in very fair working order.

Mr. F. J. Bramwell said, in reference to Mr. Phipps's ingenious theory in support of the opinion, that the wear of the rails was as the square of the speeds, that he was inclined to think that the end of the calculation had not been reached, as it was assumed that the displacement of material must be equal at all speeds, and that if it were done at double velocity, it must take four times the power to do it, and therefore the wear must be four times. Was it not probable that the material was not displaced equally for all speeds, but that at the higher speeds there was less displacement, because the displacing force had a shorter time in which to act? As the resistance of the air increased as the square of the speeds, and as the whole resistance on a level was compounded, principally, of that of the air and of the work on the rails, if the wear of the rails were as the square of the speeds, ought not the whole power required to draw a train to be also as the square of the speeds? Practically this was not the case, and therefore the portion representing the work on the rails could not increase as the square of the speed. It seemed to him, therefore, that the theory on that point could not be accepted.

As to the reason why a suspended joint was better than a joint upon a chair, he might remark that if it were wanted to hammer out a bar of iron cold, the operation would not be begun by hammering at the middle of the bar, but the end would be attacked as the most vulnerable point; the reason being, that any particle in the middle of the bar had the support of the particle on each side of it, while at the end of the bar there was support on one side only. The same reason applied to the joints of rails. It must be evident, that the end of the rail was the most vulnerable point, and therefore, the part which, of all others, should not be over an anvil, such as a chair, but should be over a void, as when so placed, and supported only by the fish plates, it would yield under the hammer-action of the train, and not get punished. But when the ends of the rails were on chairs, then they got hammered out, as was evident by their widening out into the fan shape, so almost invariably seen when the joints were supported on chairs; but when suspended joints were employed, the ends of the rails were found to be hardly widened out at all, even after long use.

Mr. PHIPPS explained, that he was perfectly aware, when he propounded the doctrine of the destructive effects of speed being as the square of the velocity, that the objection would be made of its not corresponding with the usual notion respecting friction, namely, that the friction of solid bodies was as the simple velocity and not as the square; but it was quite easy to conceive that whilst the major part of the resistance on railways, exclusive of the resistance of the air, was simply as the velocity, the remaining part of the resistance, containing the destructive element he had referred to, might increase in the ratio of the square.

Mr. W. H. BARLOW said, there were one or two points to which he wished to refer, more especially as to the time of duration of an iron rail. It was stated in the Paper to be three years, with a traffic of 63,000 tons. Now from his experience on the Midland Railway, he had reason to suppose the wear of a rail was from 100,000 to 150,000 tons, depending upon weight, speed, and other circumstances; and if it was so low as 63,000 tons, he thought there must be some defect to be accounted for by other causes.

In connection with the destruction of permanent way, there was one element which had not been previously referred to: that was the imperfect fitting of the parts. He had noticed one or two cases of that. In one instance, where the line, or part of it, was relaid with sleepers of superior quality, he was surprised to find within twelve months a report was sent to him, that the chairs were burying themselves into the sleepers. On inquiry it turned out that in a fit of economy, the old spikes had been used in relaying the new chairs. These spikes had been worn at the necks, and the consequence was motion of the chairs, which gradually became indented into the sleepers. Another example was in an endeavour to fish old rails with new fish plates. He confessed that fishing was of great benefit; but it would not do everything, and it would not do to fish old rails, as movement took place, which acted with great disadvantage.

On the question of experiments on steel, he agreed as to the great importance of getting reliable information on the subject. Two or three years ago, he obtained permission to make use of the Government testing-machine at Woolwich Arsenal, for the purpose of experiments on steel. These were carried to a certain length, and included tension, compression, transverse strain, and torsion; but unfortunately, the machine was not upon that scale which could bring out sufficiently satisfactory results. The experiments on tension were pretty clear, and agreed with those described by Mr. Berkley. The experiments on compression were better, inasmuch as they were made upon cylinders of 1½ inch in diameter, and the results were corresponding. The experiments on transverse strain did not agree, as they showed the deflection of steel to be as great as that of iron; but the capability of the former, of being bent to a greater extent before the elasticity gave way, was very great indeed. The differences in these respects showed the necessity for further inquiry into the subject. He should be happy to assist in any experiments for ascertaining the strength of steel under various strains, for which purpose Mr. Kirkaldy's machine appeared to afford great facilities and advantages.

Mr. F. W. WEBB said, in a short time arrangements would be completed at Crewe for the manufacture of 350 tons of steel per week, 300 tons of which would be used for rails. At present there were 50 miles of steel rails in use on the London and North Western Railway, and about 3,000 tons of the compound, or steel-headed rails. At Crewe, the main line, on both sides of the station, had been laid with steel rails. Having recently examined those laid in November, 1861, over which 52,191,859 tons had passed, he found the wear of the rails had been $\frac{5}{16}$ths of an inch. The results of the wear of these rails did not quite come up to the rails at Chalk Farm, but there had been a good deal of shunting over these rails, as upwards of 19,000,000 tons of the total tonnage were attributable to engines and tenders shunting at the goods sidings, &c. The greatest weight on any pair of wheels was 10 tons 10 cwt., which would tell more severely upon the rails than the lighter weight per wheel of the wagons. He had also examined the two rails which were made in 1862, and were shown in the International Exhibition by Mr. Bessemer. They were

35 feet in length, and were laid on the departure side of the Crewe station, on the up-line, on the 10th March, 1863. There had passed over these rails 18½ million tons, and the wear of the rails had been $\frac{3}{32}$nds of an inch. In the latter case there had been no great amount of slipping or breaking; in the former case there was a considerable slipping of the engines and breaking of the tenders and vans that passed over the rails.

As the discussion had in some measure turned on the attachment of the rail to the sleeper, he would state that, in 1859, Mr. Ramsbottom introduced on the London and North Western Railway wrought-iron chairs and keys, which had been working successfully, in lengths varying from a quarter of a mile to two miles of road at Bletchley, Sudbury, and on the Crewe and Chester line, &c.; nearly the whole of the rails, however, were laid with the ordinary fish-joint. Mr. Ramsbottom subsequently proposed and introduced a fish-joint without bolts, which stood very well, no instance of working loose having occurred. In this plan, a wrought-iron key, long enough to reach from chair to chair, was placed on each side of the joint. In the length laid at Crewe he had found no instance of the keys having become loose, and on inquiry of the plate-layers, he ascertained that only two keys had worked loose, and that was shortly after being laid. This method of suspending the rail from the chair had proved very successful. The rail was perfectly uninjured by the chair, and the rail could be turned, if it was thought desirable to use both the top and the bottom tables. At the time these chairs were first made the cost was £9 per ton, but since then the machinery had been so much improved, that they could now be produced at a much cheaper rate. It was in contemplation, by the London and North Western Company, to employ some of the old iron rails for re-rolling into chairs, instead of using cast-iron chairs. As the rail was suspended in the chair, on the upper web, there was no bottom bearing, so that the bottom table of the rail remained uninjured. In his experience he had not found rails break after being turned. The chief defect was the jolting motion in consequence of the indentation. No accident had occurred on the London and North Western through turning the rails.

Mr. JOSEPH CUBITT said, on the Great Northern Railway when new iron rails were first turned, after being about four or five years in the road, they broke to a very great extent, but he had never experienced it to the same extent in any other case. He supposed the metal had become deteriorated by the rolling.

Mr. WEBB said, in his case the rails were chiefly re-rolled ones, and they were found to be very fibrous in the middle of the section.

Mr. T. E. HARRISON said, the result of his experience with regard to turned rails was different to that mentioned by Mr. Cubitt. He had had rails turned constantly for years, and by adopting the plan of using a wooden cushion, which prevented indentation of the rail by the chair, he had not had reported to him a single instance of turned rails having broken. There must, therefore, be something beyond the mere turning which led to the, he believed, general impression that turned rails were sure to break.

There were some points suggested in the course of this discussion, which induced him to offer a few observations upon the subject generally. In the first place, Mr. Bessemer remarked that steel rails might be rolled of lighter weight, so as to reduce the cost to the same amount as iron rails. Now, for his part, he would never advise any railway company intending to adopt steel to follow that suggestion; because the weight of iron rails had been gradually increased, till they had arrived at 80 lbs. or 82 lbs. to the yard as a maximum; and it was probable even heavier rails might have been adopted, but the manufacturers seemed to be of opinion, that beyond that weight it was not possible to insure a rail absolutely solid and sound. He thought, by using steel for the heavier section of rail of 80 lbs. or 82 lbs. to the yard, that would only be another step towards perfection in the permanent way, which all who had to maintain lines of railway must look upon as a most essential object.

With regard to the use of steel rails, that was a question which ultimately with all railway companies must be reduced to a question of pounds shillings and pence; and though there were numberless cases in which iron rails did not last more than three years, yet there were instances within his own experience in which they lasted for twenty years, and then the question of compound interest became an essential element in the calculation. It was clear, that unless the cost of steel rails was much reduced, it could not be expected that they would be universally adopted; but at the same time, the instances in which they had been, and were daily being, used with great economy were very numerous—as at stations and places where there was a great deal of running of engines backwards and forwards. In such cases where ordinary rails would not last more than three or four years, from his own experience of steel rails (not Bessemer's make) there was three or four times the wear of ordinary rails with absolute certainty. The price of steel rails—as was the case with all new manufactures—had been rather high, but he found it was gradually going down. He had recently contracted for 500 tons of steel rails at £12 10s. per ton, which was getting towards a more moderate price, and as that went on, he had no doubt the use of these rails would be extended. He recollected having paid as much as £17 per ton for rails made of refined iron by a special process; but in those days the weight was not more than about 30 lbs. to the yard; then there was no hesitation as to the cost, the only anxiety being to have the best material. The original rails on the Newcastle and Carlisle Railway cost £17 per ton. When taken up, after a number of years' wear, and offered for sale, the demand for them was so excessive, that twenty times the quantity could readily have been sold, but rails of that quality had not been made during the last twenty years.

As to the form of rail and the mode of construction, Mr. Harrison stated, that he had taken up rails of every variety of form. Rails laid on the Hull and Selby line by the late Mr. Walker, thirty years ago, had been taken up within the last three or four years, and he had to consider the desirability of re-laying the road upon the same plan. The circumstances, of course, after a period of thirty years, were entirely different. The traffic had increased enormously, and, looking to all the circumstances, he came to the conclusion, that laying the line with cross sleepers, double-headed rails and cushions was infinitely better than laying it on the original plan; and on the North Eastern line, though there were formerly a great many miles on that system, yet at the present moment there was not a single mile of it. Before determining not to use it, he thought it necessary to go fully into the question, examining not only those who had charge of the permanent way as foremen, but those who had the actual maintenance of the road. In some cases, with a small traffic, it might be a useful kind of line; but looking to all the circumstances, his conviction was that, in the long run, the cross-sleeper line would be found to be the best. The flat-bottomed rails had been laid both on longitudinal and on cross sleepers on the Hull and Selby line, but they were not fish-jointed. The whole of the timber had been subjected to some preservative process, and the longitudinal timbers were so sound, that he actually laid a new set of rails and chairs upon the old sleepers that had been down for twenty years. There appeared to be a prejudice against creosoting, but he for one still adhered to it. He certainly thought there must be something peculiar which had induced those who had hitherto used creosoted sleepers to discontinue their use. In his own experience, he found no sleeper was better for wear than the ordinary Scotch fir sleeper creosoted. It was tougher than others, and would stand the resetting of the chairs, and pins might be driven into it two or three times without splitting. The great defect of the ordinary Baltic sleeper cut down the middle, was the splitting from the pins; but notwithstanding that, he thought it was a mere question of wear. Such a chair as Mr. Hemans had described, with so small a base, would be sure to wear into the sleeper. He had adopted a base of chair at least half as broad again as that; and if the chair had a large base, and was firmly bedded on the sleeper, his experience went to show, generally speaking, that the sleepers would last for a great number of years. There were creosoted sleepers still in use on the Stockton and Darlington line which had been down for more than twenty years. Then when a sleeper became split or indented by the chairs, there were many other useful purposes to which they could afterwards be applied. The North Eastern had an enormous amount of sidings. With 1,200 miles of main lines there were 705 miles of single line of sidings; and sleepers that were no longer useful for the main line were, if creosoted, applicable for the sidings; therefore to discontinue creosoting was, from his experience, an unwise policy. On an extensive railway there was always some purpose to which worn creosoted sleepers might be beneficially applied.

As to the asserted additional wear of the rails on a down incline, no doubt when running down an incline, the rails had a tendency to go down the incline themselves. But having lately examined the diagrams,—which had been kept for many years, and were similar in principle to those exhibited,—showing the wear of the rails, and the dates at which they had been renewed, on every portion of the North Eastern Railway, he found, that though on some of the inclines, the steepest being 1 in 120, there was a slight difference in the wear of the down line, yet it was so slight that he thought the increased wear upon the down incline on the Great Northern could not be attributed to the fact of its being on an incline; but it appeared to him to be owing to the much heavier weight of traffic to London, including the whole of the large mineral traffic. Then there was a further cause which, on the Great Northern, might have some effect. There were many tunnels which were blocked if there was anything in them, or a train immediately preceding, and the train could not be stopped without the application of the breaks. In travelling on that line, he had found it to be frequently the case that, from tunnel to tunnel, the breaks were applied, and that no doubt helped to wear the rails, and he attributed the additional destruction of the rails to that cause, more than to the fact of its being a down incline. He found further, that between York and Darlington, where there was a large mineral traffic towards York, there was unquestionably a difference in the wear of the up-rails; in that case the speed in both directions was equal. For 45 miles the ruling gradient was 1 in 1,000, therefore the theory of the steep gradient could not be applied in that case; and though no doubt the traffic towards York wore more than that coming from the south towards Darlington, yet the difference in the wear was less than he would have expected. A curious fact had been recorded by the resident engineers of the northern and southern divisions of the North Eastern line, viz., that the men who acted as platelayers in the northern district of Northumberland, would do a great deal more work than those who were engaged in the southern districts of Yorkshire. In the one case the men seemed to work with a natural vigour; they stripped to their work and seemed as if their whole soul was in it; but as they got towards the south, the same energy and love of the work was not manifested as in the north of Northumberland. Whether there was the same difference in the amount of work got out of the men as they came further south he could not say.

In conclusion, having had full opportunity of going into all the details, he did not think a Paper had ever been presented to the Institution which had been prepared with more accuracy, or with more complete detail, or with a greater determination to make it a perfect one. For himself he would say, that he felt under great obligations to the Author, for having brought so important a subject before them in so admirable a manner.

Mr. G. W. HEMANS explained, that his suggestion with regard to the obvious advantages of continuous bearings for the permanent way had been condemned upon what, he thought, were false premises. It appeared to be assumed, that the permanent way he recommended had been tried, taken up, and condemned. He believed that system of permanent way had never been tried, in a perfect form, and that it was deserving of a trial. A heavy rail with a flat surface at the bottom, laid on longitudinal sleepers, and well fished at the joints with deep fishes had never, to his knowledge, been laid and subjected to a fair trial, except, in a not very perfect manner, for a short distance at the Victoria Station, and which he believed was a very successful piece of permanent way.

Mr. BESSEMER said, he feared he had scarcely explained clearly his views with reference to the lightness of steel rails. He intended it to be understood, not that the rails must necessarily be lightened very much, because it appeared that the increased traffic and great weight of the engines now employed were such, that the present iron rails, weighing 84 lbs. to the yard, did not admit of a great reduction being made; but as steel was found to be much stronger as a beam, and was capable of sustaining a much greater weight than iron, without deflection or permanent set, so, in estimating the actual weight of steel and iron that was required to sustain a given load, the two metals ought not to be reckoned as equal pound for pound with each other. If it was not desirable to lighten the steel rail, then in any comparative estimate, the cost of a much heavier iron rail must be taken as its equivalent.

Mr. J. S. CROSSLEY said, having paid considerable attention to the permanent way of the Midland Railway, he found that the average duration of iron rails was sixteen years; where there was a very heavy traffic about twelve years; and that the minimum life, where the rails were bedded on cast-iron sleepers, ten years; and in the latter case the rails were subject to such rapid wear on the lower sides that they could not be turned. The indentation was very considerable, from the narrow base of the bearing surface. In his own experience he never knew of a rail breaking from being turned, unless it was bad iron. He did not find that the necessary result of turning a rail, was that it must break; but when the rails were indented, there was that disagreeable motion which was caused by passing over the indented surface of the rails. On the Midland Railway the relaying of the rails, including interest on first outlay, was effected for 11*s.* per ton per annum. If steel rails at £18 per ton were used, it followed that the interest of the money rendered that material unavailable for the general purposes of ordinary lines. In certain positions, such as the entrances to stations, &c., no doubt they were useful and profitable. If steel rails, at £12 per ton, were employed, then the interest was greater by 1*s.* per ton per annum; therefore they ought only to be used in exceptional cases. But supposing the steel rails to last for ever—which he did not imagine was claimed for them—he found the calculation stood thus. Iron rails could be re-rolled for £3 5*s.* per ton. The question was the interest of the money; taking £7 per ton as the average cost of the rails, that would be 7*s.* per annum, the re-rolling 65*s.* divided by the number of years the rails lasted. If their life was sixteen years, it would be 4*s.* per ton, and if only eight years, it would be 8*s.* per ton. If a rail only lasted eight years, steel rails at £15 per ton would be the more profitable; but his own experience was, that on lines where the traffic did not exceed sixty or seventy trains a day each way, he did not think a rail of good quality would wear out in less than twelve years, and that the average life was sixteen years. He could confirm the statements of Mr. Harrison in this respect. On the Thame Valley line, rails of 68 lbs. to the yard had been in use for twenty-four years; but the quality of the iron of course had much to do with the duration of a rail.

With regard to creosoting, he was one of those who had given it up, because he did not think it answered commercially. At Grimsby good rectangular Baltic sleepers, 9½ inches by 4¾ inches, could be purchased for 2*s.* 4½*d.* or 2*s.* 5*d.* each, and those 10 inches by 5 inches for 2*s.* 9*d.* each. If 1*s.* was spent in creosoting, that at compound interest for fourteen years would be 2*s.* He had sleepers that had lasted for sixteen years, and thus there was 2*s.* 2*d.* out of the 2*s.* 4*d.*, which would pay for a new sleeper, and he got thirty-two years' wear out of the two sets of sleepers as against twenty under the creosoting process. He thought that creosoting increased the tendency to split, and on lines where the chairs had too small a bearing, the sleepers were worn through. He had seen as much as 2 inches or 2½ inches of indentation of the chairs into the sleepers: creosoting was no protection against that. He did not think the rotting of the sleepers was the only element that had to be considered in the wear of sleepers. There was the trituration of the wood, which creosoting did not prevent, and there was further the tendency to split. His own opinion was, that the money which the creosoting would cost was more than adequate to replace the injury from decay which creosoting prevented. On these grounds he had discontinued to creosote. For bridge timber and piles creosoting was valuable, for preventing the attack of the worm, but for sleepers he did not think it paid, and pounds shillings and pence were more urgent than science, in regard to the materials used in the construction of a railway. Whatever tended to reduce the dividend was not looked upon with favour by Boards of Directors. By the use of steel rails at £14 per ton the dividend on so much capital as was represented by the rails would be reduced from 5 per cent. to 2½ per cent.; but if a 70 lb. rail of steel could be adopted with equal safety and advantage as an 80 lb. rail of iron, it went very much to raise the value of steel rails in the construction of railways. From his own experiments he believed that a 70 lb. steel rail was as much to be depended upon as an 80 lb. iron rail, though he thought it better not to go back in the weight of material, because if an 80 lb. iron rail could be rolled, the same could be done in steel: the only question was, was it worth their while to do it? No doubt an 80 lb. steel rail would make a very strong road; but at the end of ten years it would be found that a great deal more had been paid for it than for an ordinary road. He considered on the whole, that the use of steel rails at present would be confined to places of great wear—as the entrances to stations and shunting-places—and there, he thought, for the present it must stop.

It was said that old steel rails were worth £10 per ton to convert into plates, &c., which were worth more money than the rails. How was it they were not made into plates in the first instance? as that was an inducement to manufacturers to jump over the intermediate twenty years. He thought as it cost about £3 to re-roll iron rails, it would cost at least £5 or £6 to re-roll steel, and assuming that a steel rail would last two and half times as long as an iron one, that was the measure of the value of steel. If it cost £12 10*s*. it would be worth £7 as scrap.

Mr. Brotherhood inquired, whether Mr. Crossley intended his remarks, with regard to non-creosoting, to apply to England alone, or whether they applied to places like India or Ceylon? He had sent out timber for forty bridges in Ceylon, to replace bridges built of lignum vitæ which had been eaten by ants, but creosoting prevented the ravages of those insects in India and Ceylon.

Mr. CROSSLEY replied that his remarks were limited to England.

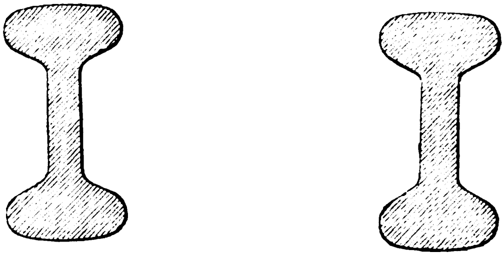
Mr. FRANK STILEMAN, in the absence of Mr. M'Clean, said, the Directors of the Furness and Midland Railway Company having requested their Engineers to advise them as to the expediency of using steel instead of iron rails, it had been decided to make a series of tests, with a view to ascertain their relative strength. For this purpose steel rails of 73 lbs. to the yard, and iron rails of 80 lbs. to the yard (for sections see next page) were keyed in chairs, placed 4 feet apart from centre to centre, and the results of the tests were shown in the following table:—

STEEL RAILS 73 LBS. TO THE YARD.	IRON RAILS, 80 LBS. TO THE YARD.
1st Test.—Set from successive blows.	*1st Test.*
5 cwt. falling 4 feet gave 0 inch set.	5 cwt. falling 5 feet gave $\frac{1}{8}$ inch set.
" " 5 " " $\frac{1}{32}$ " "	" " 6 " broke rail.
" " 6 " " $\frac{1}{8}$ " total set.	
" " 7 " " $\frac{1}{4}$ " "	
" " 8 " " $\frac{1}{2}$ " "	
" " 9 " " $\frac{11}{16}$ " "	
" " 10 " " 1 " "	
" " 11 " " $1\frac{1}{8}$ " "	
" " 12 " " $1\frac{7}{16}$ " "	
" " 13 " " $1\frac{11}{16}$ " "	
" " 20 " " $2\frac{1}{4}$ " "	
2nd Test.	*2nd Test.*
5 cwt. falling 13 feet gave $\frac{3}{8}$ inch set.	5 cwt. falling 6 feet gave $\frac{1}{8}$ inch set.
" " 20 " " 1 " "	" " 7 " " $\frac{3}{16}$ " "
" " 26 " " $1\frac{1}{2}$ " "	" " 8 " broke rail.
3rd Test.	*3rd Test.*
Dead weight of 32 tons on two rails, with base of 19 inches in centre of rails, $\frac{1}{8}$ inch deflection under load. No permanent set after removal of load.	Dead weight of 32 tons on two rails, with base of 19 inches in centre of rails, $\frac{3}{16}$ inch deflection under load. No permanent set after removal of load.

These experiments proved so satisfactory, that the Directors determined to lay down steel rails of 73 lbs. to the yard over the whole length of their railway.

With regard to the opinion which had been expressed, that though the weight of the rails, &c., had been increased, no improvements had been made in the mechanical appliances for fixing them, he thought the many Papers brought before the Institution were sufficient to contradict that statement, and the many patents used and tested by the Engineers on most of the leading lines of railway also went to show its fallacy. After all the experiments, it appeared they had come back to the old system of the chair with the key. He had adopted, on a length of 10 miles, iron keys fastened by a small bolt passing through the jaws of the chairs. These had been in use for eight years without requiring any renewals, neither had any become broken.

Fig. 2. Fig. 3.



Furness and Midland Railway.
Steel Rail, 76 lbs. per yard. Iron Rail, 80 lbs. per yard.
¼ full size.

Mr. H. W. Schneider said, being connected with the Barrow Hematite Steel Company, he would make a few remarks upon steel rails, particularly with reference to the commercial value of those rails, because he held that everything must be reduced to pounds shillings and pence, and unless it could be shown incontestably that steel rails would give at least as good a dividend, they would be put on one side and iron would be continued. He laid it down as an axiom, that they had no right to take a given weight of iron rail, and then assume that steel required to be of the same weight. What had to be done was to test the relative merits of steel and iron, and take that weight of steel which represented an equivalent value of iron. If it was necessary to increase the weight of steel, it was equally necessary the weight should be increased in iron. Following out what Mr. Bessemer had justly said, it would be found, if it were possible to reduce the weight of steel, it was simply because a 72 lb. rail in steel was practically equivalent to an 84 lb. rail in iron for all the purposes of the daily traffic; but then came the more important point, whether the steel rail, in the course of a given number of years, would pass through such an amount of punishing, that at the end of that time it would represent a commercial value greater than that of the iron rail. He dissented from the statement, that for £7 per ton at the present time a rail could be got in England worth anything at all. No Engineer would venture to say, he would put down rails at £7 per ton, that would last sixteen years, where there was any large traffic. He had made a calculation that the ordinary wear of a good iron rail at £8 5s. per ton would be fourteen years with a fair traffic; and he was convinced, from experiments he had made upon steel, and looking to the greater effect of oxydation upon iron than upon steel, that steel would wear for an almost unlimited period; but he was contented to assume that a steel rail would wear out three iron rails, lasting fourteen years each, and this brought him to the commercial point of the question. Without going through all the calculations he had made, he would say, supposing a steel rail cost £13 a ton, at which he believed steel rails might be produced, it would be found that, compared with iron rails at £8 5s. per ton, there would be a saving of £8 per ton of iron rails at the end of forty-two years, reckoning 5 per cent. compound interest during that period, and adding £3 10s. each for two renewals of the iron rail necessary to make it last the forty-two years. He assumed that at the end of the forty-two years, the steel rail would be worth £7 per ton, not £10; but he went further and said, following up that calculation to a ten years' life of an iron rail, for heavy traffic, and assuming, as he might do, without contradiction, that a steel rail would last for forty years, against four renewals of ten years each of iron, there would be a saving of £15 per ton of iron rails, or £1,500 per 100 tons of iron in the steel over the iron. In that calculation he had assumed that 85 tons of steel rails would practically represent 100 tons of iron rails. He did not enter into the question, whether it was possible to reduce the weight of the rail, but he said if it was necessary to have steel rails of 84 lbs. to the yard, it was equally necessary that the weight of the iron rails should be increased from 84 lbs. to 100 lbs. to the yard.[1]

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[1] The comparison between steel rails in England against iron rails stands thus: taking steel rails at £13 per ton and iron rails at £8 5s. per ton, and assuming that steel rails weighing 15 per cent. less than iron are stronger than iron rails, that iron rails of the best quality, with ordinary wear, will not last more than fourteen years, that it costs £3 10s. to convert a ton of old rails into an equal weight of new, and that steel rails for this work will wear out at least three iron rails:—

IRON RAILS.

		£.	s.	d.
100 tons of iron at £8 5s.		825	0	0
14 years at 5 per cent. interest on £825—£41 per annum .		574	0	0
		1,399	0	0
100 tons reworked at £3 10s. =	£350	350	0	0
First cost . . .	825			
	£1,175			
14 years' interest at 5 per cent. on £1,175—£58 per annum		812	0	0
Carried forward .		£2,561	0	0

With regard to the presumed folly of steel manufacturers making steel into rails and selling them at £13 per ton, when the old rails could be worked up into another form, and be sold at a higher rate, that was, no doubt, upon paper a very pretty theory, but in practice it had this essential defect, that it was not economical, for this reason; he held that the Bessemer process was one of those scientific operations which required large capital, great skill, and works of great magnitude, before it could be hoped to carry out the process with anything like satisfactory results. The consequence was, having to deal with quantity, the manufacturer must look to that article which would take up the largest quantity and weight, and that undoubtedly was rails. But, nevertheless, the fact was perfectly true. He had himself seen the ends of rails shorn off, utterly unfit for practical purposes, put under a 3-ton hammer, split in two, heated, and wrought into a miner's pick, which had lasted as long as five picks made from iron, for which £22 per ton had been paid; the iron pick requiring steeling, and the other only requiring to be put into the fire and sharpened. This proved that the refuse of steel rails might be converted into a very valuable article, which sold at the moment for a higher price than the rails. Again, he could not see why it should be inferred, that whilst iron rails could be re-rolled for £3 10*s*., it would cost

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					£.	s.	d.
Brought forward .					£2,561	0	0
First cost and one renewal .	£1,175						
Second conversion .	350				350	0	0
	£1,525						
Interest—14 years, on £1,525, at 5 per cent.—£76 per annum					1,064	0	0
					£3,975	0	0
STEEL RAILS.							
85 tons of steel at £13 . . .		£1,105	0	0			
5 per cent. interest = 55 × 42 years .		2,310	0	0			
		3,415	0	0			
Value of steel at the end of 42 years; 85 tons at £7 per ton . .	£. 595						
Value of iron ditto 100 tons at £3 10*s*.	350						
		245	0	0			
					3,170	0	0
Saving on steel equal to £8 per ton, or £800 .					£ 805	0	0

In any case this saving is much increased by the cost of relaying the rails and the superior strength; but in the case of foreign lines, and India especially, where there are not the same facilities for reworking the iron rails, this saving is multiplied to a large extent. The question of carriage is also an important one. At stations, the advantages of steel are too self-evident to require any remark, and it is by no means an established fact, that steel rails will not last much beyond forty-two years, and on the other hand, it is certain that where there is a large

£5 per ton to re-roll steel rails. All the expensive portion of the process of the manufacture of steel rails had been passed before the material reached the rolling mill. If an old steel rail was worked in the same way as an old iron rail, he was satisfied it could be done, if not quite as cheaply as iron, within a very few shillings per ton, and these few shillings would be added to the steel, because the waste was upon the higher-priced article, and therefore it must be added to the cost of the waste; but the cost of the re-manufacture was otherwise the same in steel as in iron. But the chief objection to steel rails he admitted was their price. It was well known that, in all new articles, before competition was introduced into the manufacture, there would be a cost additional to what the same things could afterwards be produced at; but without going into the question of the actual cost of steel rails, he thought it was hopeless to expect, that steel rails would ever be reduced to anything like the price of iron rails, as the finest qualities of pig iron had to be used, and the process was an expensive one. He believed that £13 per ton was a fair price, and he trusted that it was not a price which would deter Engineers from making use of steel rails; but beyond that, the price of steel rails would not, in his opinion, be reduced for a lengthened period to come. In making Bessemer steel, extreme care must be taken with reference to the manufacture of the pig iron in the first instance, and in the selection of the ore for the purpose, all hematite not being equally

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traffic, iron rails will not last more than ten years, when the advantages are still more apparent, thus—

		£.	s.	d.
IRON RAILS.				
Iron rails, first cost		825	0	0
Interest at 5 per cent. = £41 × 10		410	0	0
		1,235	0	0
Original cost and first renewal £1,175		350	0	0
5 per cent. = £58 × 10		580	0	0
		2,165	0	0
Original cost and two renewals £1,525		350	0	0
5 per cent. = £76 × 10		760	0	0
		3,275	0	0
Original cost and three renewals £1,875		350	0	0
5 per cent. = £93 × 10		930	0	0
		4,555	0	0
STEEL RAILS.				
Original cost	1,105			
5 per cent. = £55 × 40	2,200			
	3,305			
Less increased value at the end of 40 years .	245	3,060	0	0
Saving equal to £15, or £1,500		£1,495	0	0

valuable for this pig iron. In the next place, having selected the ore, it was desirable to test every pig after it came from the furnace, to avoid passing over from the iron works to the steel works any iron that was not of the best quality for the purpose for which it was intended.

The results of a few of the experiments made by Mr. Kirkaldy, as to the tensile, crushing, and shearing powers of the steel manufactured by the Barrow Hematite Steel Company, were recorded in the following Tables:—

TABLE 1.

ELONGATION and SET, under a gradually increased PULLING STRAIN of Four Bars of Cast Steel forged to 1½ inch diameter, and turned to 1¼ inch.

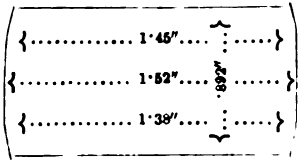
	STRAIN in lbs.																
	40,000	42,000	44,000	46,000	48,000	50,000	52,000	54,000	56,000	58,000	60,000	62,000	64,000	66,000	68,000	70,000	72,000
	·083	·087	·092	·098	·107	·129	·158	·188	·238	·310	·435	·498	·584	·684	·730	·818	·867
Set	·044	..	..	..	·057	..	·090	..	..	..	..	..	..	..	..	..	..
	·079	·084	·087	·090	·100	·115	·138	·171	·218	·281	·348	·389	·452	·502	·564	·635	·682
Set	·041	..	..	..	·052	..	·085	·113	..	..	..	..	..	..	..	..	..
	·080	·082	·086	·088	·091	·095	·098	·100	·228	·265	·378	·441	·490	·545	·603	·686	·770
Set	·044	..	..	..	·048	..	..	·051	..	·204	..	..	..	..	..	..	..
	·082	·085	·089	·092	·095	·098	·102	·112	·226	·385	·492	·520	·582	·666	·732	825	·892
Set	·045	..	..	..	·050	..	..	·053	..	..	..	..	..	..	..	..	..

	STRAIN in lbs.—*continued.*						Ultimate Strain.		Fractured.				Elongation in 14 in.	
	74,000	76,000	78,000	80,000	82,000	84,000	Total.	Per Square Inch.	Diameter.	Area.	Difference.		Total.	Per Cent.
											Area.	Per Cent.		
	·910	·984	1·05	1·25	1·47	1·84	99·528	81·108	·87	·5945	·6326	51·5	2·68	19·1
Set		..	..	..	..	..	..	..	..	..	..	..	..	..
	·778	·895	1·02	1·18	1·34	1·62	85·376	69·575	·84	·5541	·6730	54·8	2·29	16·4
Set		..	..	..	..	..	..	..	..	..	..	..	..	..
	·850	·992	1·07	1·28	1·46	1·82	85·024	69·288	·81	·5153	·7118	58·0	2·48	17·3
Set		..	..	..	..	..	..	..	..	..	..	..	..	..
	1·04	1·25	1·43	1·56	1·98	2·26	84·848	69·145	·80	·5026	·7245	59·1	3·36	24·0
Set		..	..	..	..	..	..	..	..	..	..	..	..	..
							Mean	72·279			Mean	55·9	Mean	19·2

TABLE 2.—Resistance, under a Gradually Increased Crushing Strain, of Four Cylinders of Hammered Cast Steel, turned to 1¼ inch diameter, and of the same height.

STRAIN in lbs.															Ultimate Strain.		Remarks.
80,000	88,000	96,000	104,000	112,000	120,000	128,000	136,000	144,000	152,000	160,000	167,700	175,500	183,300	191,100	Total 195,000	Per Square Inch.	
·060	·075	·090	·110	·129	·152	·180	·205	·239	·270	·299	·325	·350	·380	·405	·419	158·924	Entire.
Set	..	..	..	..	..	..	..	..	..	..	..	..	..	..	·396	..	
·062	·078	·095	·114	·138	·168	·190	·215	·248	·275	·309	·328	·362	·384	·401	·422	158·924	Ditto.
Set	..	..	..	..	..	..	..	..	..	..	..	..	..	..	·401	..	
·058	·074	·090	·109	·129	·155	·183	·214	·247	·278	·308	·340	·368	·393	·420	·434	161·557	Ditto.
Set	..	..	..	..	..	..	..	..	..	..	..	..	..	..	·411	..	
·050	·062	·079	·095	·114	·138	·159	·182	·215	·239	·268	·296	·327	·350	·379	·392	158·924	Ditto.
Set	..	..	..	..	..	..	..	..	..	..	..	..	..	..	·368	..	

Fig. 1.



In the first test, with 195,000 lbs., the cylinder had assumed the dimensions shown in Fig. 1.

When replaced in the machine, under a strain of 258,750 lbs., it changed to the dimensions shown in Fig. 2.

Fig. 2.

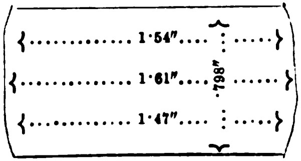


TABLE 3.—**Resistance**, under a gradually increased **Double Shearing Strain**, of Four Bars of Hammered Cast Steel, forged to 1½ inch, and turned to 1¼ inch diameter.

STRAIN in lbs.																			Ultimate Strain.	
60,000	64,000	68,000	72,000	76,000	80,000	84,000	88,000	92,000	96,000	100,000	104,000	108,000	112,000	116,000	120,000	125,000	130,000	135,000	Total.	Per Square Inch.
·058	·064	·072	·078	·484	·095	·104	·112	·122	·133	·142	·154	·168	·184	·202	·221	·250	·280	·305	140·810 {70·405 70·405	57·380 57·380
·080	·086	·092	·100	·106	·112	·122	·128	·134	·141	·150	·158	·168	·176	·190	·205	·231	·262	·298	137·620 {68·810 68·810	56·079 56·079
·069	·080	·086	·092	·102	·109	·118	·125	·132	·142	·152	·158	·172	·182	·198	·216	·238	·270	·309	137·150 {68·575 68·575	55·889 55·889

TABLE 4.—**Resistance**, under a gradually increased **Buckling Strain**, of Four Bars of Hammered Cast Steel, forged to 1½ inch diameter, turned to 1¼ inch. Length = 10 diameters.

STRAIN in lbs.								Ultimate Strain.			Remarks
32,000	36,000	40,000	44,000	48,000	52,000	56,000	60,000	Decrease.	Total.	Per Square Inch.	
·022	·025	·028	·032	·036	·040	·320	·375	0·506	63·040	51·377	Entire.
Set	..	..	·009	..	..	..	..	..	..	..	
·031	·036	·040	·162	·275	·320	·431	..	2·430	57·720	47·041	Entire.
Set	..	..	·139	..	..	..	..	..	..	..	
·020	025	·028	·030	·033	·039	·150	·184	0·852	61·472	50·930	Entire.
Set	..	..	·008	..	..	..	..	..	..	..	
·021	·025	·028	·031	·035	·118	·132	·150	0·535	63·856	52·042	Entire.
Set	..	..	·008	..	..	..	..	..	..	..	

The particulars of two experiments upon double-headed steel rails, weighing 73 lbs. per yard, manufactured for the Furness and Midland Railway, given in the next Table, would serve to show, that the great drawback attributed to steel, of being liable to breakage by sudden impact, did not exist:—

TABLE 5.—Resistance to Deflection and Set, under a gradually increased Bending Strain, of two double-headed Steel Rails. Distance between the Supports, 60 inches.

	STRAIN in lbs.																								Ultimate Strain.		Sectional Area Square Inches.	Remarks.
	13,000	15,000	18,000	20,000	22,000	24,000	26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000	44,000	46,000	48,000	50,000	52,000	54,000	56,000	58,000	60,000	Total.	Per Square Inch.		
..	·089	·109	·132	·151	·171	·192	·219	·296	·885	1·35	2·13	2·72	3·31	4·05	4·91	5·55	6·16	6·92	7·54	8·17	8·84	9·64	10·82	12·02	60·976	8·422	7·24	Canted Entire.
Set	·010	..	·021	..	·030	..	·051	·152	·701	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	
..	·095	·116	·145	·162	·180	·204	·272	·720	1·14	1·75	2·39	3·22	4·04	4·68	5·54	6·12	6·90	7·72	8·65	9·54	10·52	..	..	..	55·040	7·602	7·24	Canted Entire.
Set	·012	..	·027	..	·038	..	·158	..	1·01	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	

He exhibited a rail bent to an extent which proved its extreme ductility. He then referred to Mr. M'Clean's experiments on Barrow rails, one of which was shown; and as to the other, after the first bending the rail was straightened again and bent in the opposite direction; and after a second straightening, it was again bent double sideways, without producing the slightest fracture: all this was done cold.

In the course of the discussion mention had been made of a compound rail (partly iron and partly steel) as being, on the whole, better than either an iron rail or a steel rail, *per se*, inasmuch as it combined the hardness and wearing properties of the steel with the ductility and other properties which attached to iron, and there was a saving of cost: he ventured to disagree with that theory, for one reason; if an article could be obtained, equal to their highest requirements, in steel, he would adopt that material, because the difference in cost between a rail compounded of iron and steel, and one entirely of steel, could not be above half the difference between iron by itself and steel, by itself; and there was this disadvantage in the compound rail, that when it had to be remanufactured, it could be neither forged nor rolled with effect, because the properties of one part of the rail were essentially different from those of the other part. Therefore, commercially, the value of that rail in the market, when worn out, would be far less than the difference of the original cost of having the steel rail entire.

Mr. **Bramwell** inquired, whether it was to be understood, that there was a capability in the Bessemer rails of being piled and completely welded?

Mr. **Schneider** replied, that he had himself superintended that operation in steel of every size. He had seen steel bars put together and heated and passed through the rolls, and the weld was so perfect that he could not detect the junction. He had also seen the end of a miner's pick welded on to a new piece of Bessemer steel, in such a manner that when broken at the point of junction, it was impossible to distinguish where the weld took place. One of the great properties of the Bessemer steel was, that it would weld to itself as readily and as perfectly as iron would weld to itself.

Mr. **Webb** mentioned that, in 1860, he was unsuccessful in welding steel rails. About 50 tons of crop-ends were operated upon and rolled into rails, but though the operation seemed to have been perfect, the rails laminated.

Mr. **Schneider** added, that in 1860 hardly anybody in this country knew how to deal with the Bessemer metal. The class of metal produced then was not that which was produced now. Even Mr. Bessemer himself would admit that in 1860 his steel was very different from what it was now. What they claimed credit for now was, that they had succeeded in making steel which retained all the properties of steel with all the ductility of iron.

Mr. **R. Price Williams** said, the course of the discussion had been such as to render any reply from him almost unnecessary. He begged to thank the members for the manner in which the Paper had been dealt with, and for the approval which it had met with. He had the further gratification of thinking it had elicited a great deal of valuable information bearing upon the question, which more than compensated him for any trouble he had incurred. He could only further say, that he proposed to continue his investigations on this subject, and was anxious to impress upon the Engineers having charge of permanent way, that they would confer a great kindness upon him, by agreeing upon a little more uniformity in the mode of keeping the accounts. He would have been saved much time and trouble in compiling the information he had done, if all the permanent-way accounts had been kept on the same principle; at the same time he availed himself of the opportunity of thanking those gentlemen most sincerely, not only for the valuable information they had so readily afforded him, but also for the great kindness and encouragement he invariably had met with.

Mr. C. B. Lane begged leave, through the Secretary, to call attention to what had been designated as Mr. Phipps' ingenious theory. He maintained that a considerable class of the deteriorating effects produced by passing loads on the permanent way might be easily demonstrated to increase as the square of the velocity. He alluded to the effects arising from concussions, due to imperfect arrangements generally, but more especially to those arising from the absence of exact coincidence between the centres of gravity and centres of rotation of the wheels. Any unbalanced weights in these bodies would exercise a certain amount of deteriorating "labouring force" upon the rails; but "labouring force" was measured by the fraction represented by the formula $\frac{\text{weight} \times \text{by velocity}^2}{2 \text{ the acceleration of gravity}}$ in which the factor velocity occurred in its second power. Any one who would calculate the number of foot-lbs. wasted from this cause over a given space at two different velocities, would find the amount to vary as the square of these velocities; thus showing the theory referred to to be not only ingenious but true.

Mr. Fowler, President, said, in closing the discussion, as it had been protracted to a great length, he would be even more brief than he had intended. The Paper was a very valuable one, and had led to a most useful discussion, and from both a great deal of information had been obtained. But the discussion had perhaps ranged over too wide a surface to be quite so satisfactory on some points as was desirable. For instance, not only had there been discussed the question of the materials of the permanent way, whether these should be of iron, of steel, or of iron rails steeled, and whether the timber should be uncreosoted or creosoted, but also, widely and generally, though not so pointedly as was desirable, the different systems of permanent way at present in use had been taken into consideration. Opinions had, in fact, been expressed by nearly every speaker on the subject of the systems of permanent way, but, as a general rule, only incidentally to the other matter in the Paper, and not as part of a serious discussion upon the best system of permanent way, as a question of construction. He hoped at some future time, and before long, this subject of permanent way—more particularly as to the methods of designing and laying it down—would be thoroughly discussed at the Institution. From his own experience he was not prepared to admit, that the best kind of permanent way had yet been arrived at, even assuming that steel rails and creosoted timber were used. If it were true that steel rails would last forty-two years, and creosoted sleepers one hundred years, as contended for in the course of the discussion, that alarming item to railway shareholders of 'renewals' would practically disappear from future accounts. But even if that were happily the case, there were still other questions connected with permanent way which had been scarcely touched upon; for instance, whether longitudinal sleepers with the bridge rail, or longitudinal sleepers with the Vignoles rail, or the longitudinal road that in these days would be laid with the deep Vignoles rail with fished joints (for he believed that had never been laid in a manner, and of dimensions suited to the present weights and speed of traffic), or a cross-sleeper road with a double-headed rail on chairs, or the bridge rail laid as in Ireland, or the cross-sleeper road with the deep Vignoles rail with a good fish,—which of these methods, under different circumferences, might or might not be the best, was a matter he should like to be thoroughly discussed, and not as it had been (with no fault on the part of any one) incidentally to the other purposes of the Paper. There had been no opportunity of comparing one system with another, as the cases alluded to were not parallel cases. The light road taken up on the North Eastern, and replaced by rails of a heavier description and chairs with a wider base, was not a parallel case, or a real comparison. It was a remarkable circumstance that, except in this country, the Vignoles was almost the only form of rail used; and it was employed on the main lines of France, where the traffic was as heavy and the speeds as high, as on most of the main lines of railway in this country; while the rail which appeared to find so much favour here had been, on full trial, discarded by the Engineers of every other nation. There might be good reason for this, but it was clear there was something in this question which required to be further considered and further discussed. He had in his possession a mass of information as to the various systems of permanent way in use in every country in the world at the present time, which he should be happy to present to the Institution. It must not be thought that the subject of the permanent way of railways was by any means exhausted; for valuable as the information already obtained undoubtedly was, much yet remained, which might be profitably discussed on a future occasion.

March 27, 1866.

JOHN SCOTT RUSSELL, Vice-President,
in the Chair.

The discussion upon the Paper, No. 1,152, "On the Maintenance and Renewal of Permanent Way," was continued throughout the evening, to the exclusion of any other subject.

In pursuance of the notice on the card of the Meetings, it was proposed, and resolved unanimously:—

"That in order to insure a fuller attendance of Members than could be obtained on Easter Tuesday, the Meeting be adjourned until Tuesday evening, the 10th of April."

April 10 and 17, 1866.

JOHN FOWLER, President,
in the Chair.

The discussion upon the Paper, No. 1,152, "On the Maintenance and Renewal of Permanent Way," was continued throughout both evenings, to the exclusion of any other subject.

The following Candidates were balloted for, and duly elected on April 10th:—THOMAS WILLIAM ARMSTRONG, JAMES EASTON, Jun., JOHN ELLACOTT, WILLIAM HANSON, THOMAS PATERSON, JOHN RAMSBOTTOM, and WILLIAM SHELFORD, as Members; JAMES LLOYD ASHBURY, GEORGE BOHN, Captain EDWARD KILLWICK CALVER, R.N., WILLIAM YOUNG CRAIG, WILLIAM IRLAM ELLIS, Major CHARLES PASLEY, R.E., HARRY STEPHEN THOMPSON, Lieutenant CHARLES WARREN, R.E., JAMES EDWARD WHITING, M.A., ROBERT WINGATE, and WILLIAM HENRY WOODS, as Associates.

April 24, 1866.

JOHN FOWLER, President,
in the Chair.

No. 1,162.—"On the Maintenance of the Rolling Stock on the Cologne-Minden and other Prussian Railways." By THEODORE ANTHONY ROCHUSSEN, Assoc. Inst. C.E.

IN the course of the previous session, during the discussion on the cost of maintaining the rolling stock of the North Eastern Railway,[1] it occurred to the Author, that a statement of the comparative results experienced upon some continental lines, on which a similar mineral and passenger traffic was conveyed, might prove of general interest, and, at the same time, afford the means of eliciting from the Members of the Institution information of a valuable kind. With that view he has selected for examination the following railways, which are probably well known to most English Engineers, the Cologne-Minden, the Bergish-Maerkish, and the Rhenish; and he has illustrated his remarks by a series of tables.

The Cologne-Minden Railway forms, in its northern section, the main artery of traffic to the north and north-east of Europe, by connecting the French, the Belgian, and the Dutch systems with Hamburgh, Bremen, Berlin, the Baltic ports, Russia, and the north of Saxony and Bohemia; while on the southern section, it brings to the Rhine a portion of the south German passenger traffic, and the rich minerals and pig-iron from the Siegen district. The former section passes through soil alternately sandy or loamy, and has neither steep gradients nor sharp curves; but the southern section, to Siegen and Giessen, encounters not only these difficulties, but the obstacle of tunnelling through rock; hence the cost of working this part of the line reduces the profit of the whole undertaking to the lowest limit allowed by the Charter, a dividend of 20 per cent.

The Bergish-Maerkish Railway runs in an easterly direction from Dusseldorf on the Rhine to Elberfeld and Barmen, and thence traverses that great hive of iron and coal industry, Westphalia; with a branch south to the Siegen district, and two northerly branches to connect the coalfields of Westphalia with the Rhine, Holland, and the northern parts of Europe. On the principal portion of its main line, and on the southerly section from Hagen to Siegen, this railway meets with all the difficulties of the southern section of the Cologne-Minden line, and may be said to traverse solid rock for more than two-thirds of its length.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiv., p. 459.

The Rhenish Railway, from the Belgian frontier to Aix-la-Chapelle and Cologne, thence south to Bingen, is the principal means of communication with the south and south-east of Europe. On the left bank of the Rhine it extends to Holland and the north of Germany, crossing the river at two points by means of pontoon bridges, remarkable for simplicity, efficiency, and cheapness of construction. The soil near the junction with the Belgian line, and for a large portion of the southern section is strong, and near Aix-la-Chapelle there is a heavy gradient; but the northern section is over a soft loam, similar to that of the Cologne-Minden line.

The general circumstances of the three railways under consideration are therefore not unlike. Each has its especially favourable and unfavourable features. The rails at present in use are essentially similar, being single-headed, 5 inches high, with a fine-grain iron, or steel table, and fibrous iron in the bottom. The weight is 74 lbs. to the yard, and the joints are supported. Originally double-headed rails were used, but they are now discarded.

The sleepers, which are 8 feet long, and of rectangular section, 11 inches by 6 inches, are of oak creosoted, and are bedded in gravel from 9 inches to 18 inches deep, according to the soft, or hard nature of the ground.

On the Bergish-Maerkish Railway the sleepers are laid on broken slag from blast-furnaces, and the result, as regards the wear of the sleepers, has been favourable, as may be seen by reference to Table H, column 10.

In explanation of the Tables, it is necessary to observe that A, which gives the data of the general circumstances of the lines, B, the description of engines in use, K, the commercial results, and L, the reserve fund for renewals, are intended only to illustrate the general working state and resources of the different railways; both of which conditions exercise indirectly an important influence upon the material in use.

In Table C, which gives the mileage of all the engines, column 2 shows the average number of miles which each engine has run when doing work and earning money, or the so-called profit mile. Column 4 shows the number of miles run in the service of trains while actually on their way to their destination, but during a portion of which the engine was running without load. Column 6, the station-work, estimated at five miles' run, for every hour in steam; and Column 7, the ultimate mileage per engine. But in all the calculations, the engine is only credited for the performance of profit miles; and this system is also applied to the work done by carriages and wagons; the figures in Table G only applying to the miles run in loaded trains.

In Table D, all the expenses connected with the several departments are included under their respective headings, with 5 per cent interest per annum, on capital invested in buildings, travelling expenses, &c.

Tables E and H embrace all the expenses of the workshops, interest of capital invested in buildings, machinery, and tools, with proper allowance for depreciation.

Table G gives the cost of the principal portion of the carriage and wagon stock, together with the work done in the year 1864, further illustrated in its actual result by Table K.

Table L has been added to complete the elucidation of the financial method of administration; while the more important Table, H, generalizes the cost of the maintenance of the rolling stock during the year 1864.

Tables M, N, and O are compiled from the records of the Cologne-Minden Railway for the twenty years from 1845 to 1864 inclusive, and give, in detail, the results of observations upon about twenty thousand tires, of different makers and of different materials. It is this branch of the subject which the Author wishes to bring prominently before the Institution.

The Prussian Railway Company, soon after its formation, undertook a series of experiments, in order to improve the construction of the carriage-wheels, with a view both to the comfort of the passengers and to the economy of material. The first aim was to preserve the circular shape of the wheel. A number of axles were experimentally fitted with a wooden disc, first brought forward by Mr. Daelen, principal Engineer of the Hoerder Works. This wheel answered so well in every particular, in the easy oscillation of the carriage, in the absence of dust, and in the due support of the tire, that the replacing of the old spoke-wheels by discs became simply a matter of time.

As the transition from the practice of the ordinary road to that of the railway was gradual, it was natural that the form of wheel in use on the mail-coaches and other large vehicles of that period should be adopted for railway carriages, substituting iron for wood, in order to meet the greater weight on the axle; and as the wooden spoke preceded the iron spoke wheel, so the experimental wooden disc gave rise to the iron disc.

The first form of iron disc, adopted in 1848, was that of a bulged star. A wrought-iron plate, flanged to form the periphery of the wheel, was indented with five triangular bulges from the boss, which was cast on the plate forming the disc. This description of wheel has proved very durable, most of those first made being still in use, though transferred from passenger carriages to wagons; but, owing to the combination of wrought and cast iron, it is noisy, and the boss having a diameter of 11½ inches, makes the structure heavy. It however supported the tire evenly and well, and there is now in London a pair of these wheels, with iron tires, which have run 116,000 miles without yet requiring turning; and which promise, being still 1⅝ inch thick, to last up to 250,000 miles. In order to obviate the before-named defect, of combining wrought iron and cast iron, the dished wrought-iron disc was introduced, in 1852. With the progress then made in rolling and forging, the manufacture of this wheel was both cheap and expeditious. In practice it proved less noisy than its predecessor; but the fine-grain iron necessary to insure a sound flanging for the periphery of the wheel made it too rigid. Henceforth, attention was directed to the means of obtaining elasticity both in the form of the disc and in the material used. As a first step, fibrous iron was employed instead of fine-grain iron, and the flat, or dished, disc was corrugated. The fibrous iron not admitting of sound flanging, the periphery of the wheel was formed by a rim of fine-grain angle iron, riveted to the disc plate. The success of this experiment inaugurated the gradual improvement in the application of elastic disc wheels. The only disadvantage consisted in the weakness of the riveted joint to the rim; but this was remedied in 1862, by welding the disc and the rim together.

About the same time, the Bochum Company introduced steel castings, in the corrugated form, of combined disc and tire, the experience of which is given in Table O, columns 1 to 17. The principal arguments against this wheel have been its great expense, unnecessary strength and rigidity of disc, its liability to 'run hot' with breaks, and consequent danger of flying, and its noisy vibration.

The corrugated wrought-iron disc of 1862, leading up to the improved form of 1864, is manufactured with a view of obtaining the greatest amount of elasticity which circumstances will allow. The iron used is highly fibrous. Several slabs are forged to the shape of a double cardinal's hat; this bloom is re-heated twice, and, by frequent and quick rolling, is enlarged to a diameter of about 3 feet. The rim is welded on under the steam-hammer, which at the same time punches the hole in the boss for the axle, and gives the form of the wave to the disc plate. After turning up the rim, the tire is shrunk on and bolted. Since 1864, however, the tire, whether of steel or of iron, has been welded on to the disc wheel, at first under the steam-hammer, but lately, and more efficiently, by hydraulic pressure. In this form, it is believed, the disc wheel offers the greatest amount of strength; the fibrous iron gives elasticity, the tire is supported in every part; there are no joints, bolts, or rivets to wear loose, and after the tire has been worn out, it is simply necessary to turn it down to the thickness of an ordinary wheel-rim, and to shrink on another tire. But it may be safely assumed, that, with steel tires, these wheels, in their first stage, will run from 300,000 to 500,000 miles before requiring a new tire.

Since 1862, the steel tires of the Cologne-Minden Railway have been ground instead of turned, and the nicety with which the skin of the tire can be reduced has caused a further duration in wear of between 50,000 and 60,000 miles, as compared with turning on the lathe. At the workshops in Dortmund, stones are used of from 2 feet to 2½ feet in diameter, making 500 revolutions per minute; and the revolutions are increased in the inverse ratio of the diameter of the stone, up to about 800 revolutions for a diameter of 1½ foot. The wheel makes one revolution per minute. One stone, costing on an average five shillings, will grind three tires per day, and last sixty tires. To carry off dust and grit, an exhauster is provided, the fan of which makes 1,350 revolutions per minute.

In compiling these statistics, the Author regrets that space does not allow him to add the results of the experience obtained from the iron and steel under-frames of carriages and wagons. His aim has been especially to deal with fine-grain iron and steel tires, to assist in removing the prejudice existing against a new material, and to point out that good metal, being at all times more efficient, although more expensive in first cost, forms the cheapest construction in the end.

The Paper is illustrated by several diagrams, and by a series of Tables, which will be found in the Appendix.

[APPENDIX.

APPENDIX.

TABLE A.—GENERAL CIRCUMSTANCES.

NAME OF RAILWAY.	1 Length.	2 Number of Stations.	3 Cost per Mile.	4 Weight of Rails.	5 Number of Sleepers.	6 Number of Engines.
	Miles.	No.	£.	Tons.	No.	No.
Cologne-Minden .	332·3	67	26,972	76,200	1,112,083	244
Bergish-Maerkish .	225·4	56	23,271	41,460	614,474	121
Rhenish	250	56	23,013	45,460	658,607	104

TABLE B.—DESCRIPTION of ENGINES.

NAME OF RAILWAY.	1 Diameter of Cylinder.	2 Stroke.	3 Diameter of Boiler.	4 Length of Boiler.	5 Number of Tubes.	6 Heating Surface in Fire-box.	7 Heating Surface in Tubes.	8 Total Heating Surface.	9 Pressure of Steam.	10 Diameter of Driving Wheel.
	Inches.	Inches.	Ft. In.	Ft. In.	No.	Square Feet.	Square Feet.	Square Feet.	lbs. per Sq. Inch.	Feet.
Cologne-Minden .	15	20	3 9	11 9	165	59	863	922	104	5½–6 (2)
	16	22	3 9	13 6	160	62	978	1,040	104	4½
	17	22	3 9	13 6	160	68	1,070	1,138	104	4½
	14	20	3 7½	10 6	112	45	530	575	104	3 8 in.
Bergish-Maerkish .	16	24	3 9	13 6	182	69	1,027	1,096	104	5 (4)
	17	24	4 0	13 6	197	74	1,112	1,186	104	4 2 in. (4)
Rhenish	15	20	3 9	11 0	160	63	795	858	104	5½
	16	22	3 9	10 9	160	62	795	857	104	4½
	17	24	4 2	13 8	178	74	1,113	1,187	104	4 2 in.

NAME OF RAILWAY.	11 Diameter of Running Wheel.	12 Wheel Base.	13 Weight on Drivers.	14 Weight of Engine with Water.	15 Weight of Tender.	16 Diameter of Driving Axles.	17 Diameter of Axles of Running Wheel.	18 Diameter of Axles of Tenders.	19 Consumption of Coke per Profit Mile.	20 Cost of Engine with Tender.
	Ft. In.	Ft. In.	Tons.	Tons.	Tons.	Inches.	Inches.	Inches.	lbs.	£.
Cologne-Minden .	3 6	15 6	12	28	18	6 1/16	5¼	4⅞	21	2,475
	3 4	11 2	24	31	18	6 11/16	5 11/16	4⅞	34	2,500
	3 4	11 2	24	32	18	6 11/16	5 11/16	4⅞	37	2,520
	3 8	12 0	24	31	..	7	5¾	..	48	1,900
Bergish-Maerkish .	3 4	11 0	19½	28½	17½	6	5	5	30	2,550
	3 1	11 0	26	32½	17½	6	5	5	32	2,610
Rhenish	3 4	13 0	14½	29	17½	6¼	5¼	4⅞	16	2,385
	3 4	13 0	29	39½	..	7	5¾	..	38	2,100
	3 4	11 0	26	29	17½	7	5¾	4⅞	28·5	2,790

TABLE C.—WORK done by ENGINES in 1864.

NAME OF RAILWAY.	1 Profit Mileage of all Engines.	2 Profit Mileage per Engine.	3 Train Mileage of all Engines.	4 Train Mileage per Engine.	5 Station and Shunting Work of all Engines.	6 At Five Miles, equal to One Hour.
	Miles.	Miles.	Miles.	Miles.	Hours.	Miles.
Cologne-Minden . . .	3,143,346	12,882	3,331,242	13,652	466,473	2,392,365
Bergish-Maerkish . .	1,627,044	13,447	1,771,247	14,638	154,539	772,695
Rhenish	1,569,562	15,092	..	..	144,491	722,255

NAME OF RAILWAY.	7 Ultimate Mileage per Engine.	8 Consumption of Coke per Ultimate Mile.	9 Consumption of Coke on Profit Mile.	10 Average Number of Axles per Train.	11 Average Number of Axles in Express Trains.	12 Average Number of Axles in Ordinary Trains.	13 Average Number of Axles in Goods Trains.
	Miles.	lbs.	lbs.	No.	No.	No.	No.
Cologne-Minden . .	23,457	20·1	32·0	48·07	16	21	81
Bergish-Maerkish . .	21,025	20·6	31·45	41·22	18	19	63
Rhenish	22,037	22·0	33·0	28·0	16	17	60

TABLE D.—COST of MOTIVE POWER.

NAME OF RAILWAY.	1 Salaries and Wages per Mile.	2 Repairs and Renewals.	3 Fuel and Water.	4 Oil, Tallow, and Cleaning.	5 Total per Profit Mile.	6 Total per ultimate Train Mile.
	d.	*d.*	*d.*	*d.*	*d.*	*d.*
Cologne-Minden .	3·05	3·35	2·15	0·69	9·29	5·04
Bergish-Maerkish .	2·07	3·8	1·87	1·62	9·36	5·98
Rhenish	1·93	2·61	1·9	0·97	7·41	4·62

TABLE E.—REPAIRS and RENEWAL of ENGINE TIRES.

NAME OF RAILWAY.	1 Repairs of Driving Wheel Tires.	2 Repairs of Running Wheel Tires.	3 Repairs of Tender Tires.	4 Renewal of Driving Wheel Tires.	5 Renewal of Running Wheel Tires.	6 Renewal of Tender Tires.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Cologne-Minden .	98·1	115	60·47	39·88	34·88	17·7
Bergish-Maerkish .	109·0	120	72·4	30·7	34·8	30·4
Rhenish	89·0	101	98·0	24·0	25·5	21·7

TABLE F.—SUMMARY of REPAIR and RENEWAL of ENGINES.

NAME OF RAILWAY.	1 Total Cost of Repairs.	2 Total Cost of Renewal.	3 Total Cost of Cleaning and Lubrication.	4 Total per Engine Profit Mile, including Cleaning and Lubrication.	5 On Cost of Engines.
	£.	£.	£.	*d.*	Per Cent.
Cologne-Minden .	22,890	15,340	14,510	4·04	9·26
Bergish-Maerkish .	13,971	9,655	10,948	4·7	11·38
Rhenish	7,218	3,539	3,994	3·58	7·0

TABLE G.—DESCRIPTION of CARRIAGES and WAGONS.

NAME OF RAILWAY.	1 Weight of 1st Class Carriages.	2 Cost.	3 Weight of Composite (1st and 2nd Class) Carriages.	4 Cost.	5 Weight of Composite (1st, 2nd, & 3rd Class) Carriages.	6 Cost.	7 Weight of Composite (2nd and 3rd Class) Carriages.	8 Cost.	9 Weight of 3rd Class Carriages.	10 Cost.	11 Weight of 4th Class Carriages.	12 Cost.
	Cwt.	£.	Cwt.	£.	Cwt.	£.	Cwt.	£.	Cwt.	£.	Cwt.	£.
Cologne-Minden . .	..	..	202	485	204	470	176	445	184	395	175	340
Bergish-Maerkish . .	..	..	181	450	200	460	168	435	165	370	164	315
Rhenish	200	465	160	440	..	..	180	350	150	305	153	235

NAME OF RAILWAY.	13 Mileage of Carriages used in Express Trains.	14	15 Mileage of Carriages used in Ordinary Trains.	16 Weight of 5 Ton Wagons.	17 Cost.	18 Mileage.	19 Weight of 10 Ton Wagons.	20 Cost.	21 Mileage.	22 Weight of Chaldron Wagons.	23 Cost.	24 Mileage.
	Miles.	Miles.	Miles.	Cwt.	£.	Miles.	Cwt.	£.	Miles.	Cwt.	£.	Miles.
Cologne-Minden . .	56,170	..	28,500	65	113	7,943	106	156	8,790	67	85	7,577
Bergish-Maerkish . .	..	47,160	..	82	114	12,448	99	138	13,962	..	..	..
Rhenish	27,573	..	23,095	70	105	7,147	120	135	7,147	..	..	..

TABLE H.—REPAIRS and RENEWALS of CARRIAGES and WAGONS, inclusive of Cleaning.

NAME OF RAILWAY.	1 Of First Class Carriages.	2 Of Composite (1st and 2nd Class) Carriages.	3 Of Composite (1st, 2nd, and 3rd Class) Carriages.	4 Of Composite (2nd and 3rd Class) Carriages.	5 Of 3rd Class Carriages.	6 Of 4th Class Carriages.	7 Of 5 Ton Wagons.	8 Of 10 Ton Wagons.	9 Of Rails.	10 Of Sleepers.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Cologne-Minden . .	..	10·16	9·41	..	8·72	8·66	5·7	3·65	5·42	3·7
Bergish-Maerkish . .	..	..	..	7·94	..	..	5·02	4·73	5·55	2·01
Rhenish	5·05	4·95	..	4·3	2·95	3·02	2·17	2·37	4·25	5·3

TABLE K.—COMMERCIAL RESULTS.

NAME OF RAILWAY.	1 Number of Passengers Carried.	2 Percentage of Seats occupied.	3 Distance Travelled.	4 Number, 1st Class.	5 Fare per Mile, 1st Class.	6 Number, 2nd Class.	7 Fare per Mile, 2nd Class.	8 Number, 3rd Class.	9 Fare per Mile, 3rd Class.	10 Number, 4th Class.	11 Fare per Mile, 4th Class.	12 Average Fare per Mile.	13 Total Earnings from Passengers.
	No.	Per Cent.	Miles.	No.	d.	No.	d.	No.	d.	No.	d.	d.	£.
Cologne-Minden .	3,701,360	26·2	22·94	38,904	1·78	450,707	1·06	779,479	0·79	2,324,913	0·397	0·73	258,645
Bergish-Maerkish	3,962,354	23·5	11·1	17,786	1·5	495,190	1·22	1,405,827	0·875	1,839,100	0·47	0·73	129,872
Rhenish . . .	3,643,531	34·0	21·5	280,821	1·9	1,036,455	0·96	2,085,824	0·62	240,431	0·28	0·84	274,851

NAME OF RAILWAY.	14 Total Earnings from Passengers per Mile.	15 Distance Travelled by Goods.	16 Rate per Mile for every Ton.	17 Total Quantity of Goods.	18 Total Earnings from Goods.	19 Total Earnings per Mile.	20 Total Earnings of Goods and Passengers.	21 Total Expenses.	22 Expenses in Proportion of Earnings.	23 Expenses per Engine-Profit Mile.	24 Renewal Fund.	25 Sick and Annuity Fund.	26 Dividend.
	£.	Miles.	d.	Tons.	£.	£.	£.	£.	Per Cent.	d.	£.	£.	Per Cent.
Cologne-Minden .	778	42·27	0·975	5,541,862	1,086,785	4,049	1,345,430	578,916	43·0	44·2	260,841	86,844	15⅜
Bergish-Maerkish	551	25·37	1·18	4,808,766	447,221	2,692	652,236	485,734	74·4	71·6	88,063	54,367	7½
Rhenish . . .	1,099	34·0	1·45	1,299,350	256,401	1,026	531,252	242,090	43·5	37·0	212,212	26,465	6¼ and £96,795 amortised.

TABLE L.—STATUTORY RESERVE for RENEWAL FUND.

NAME OF RAILWAY.	1 For Engine and Tender.	2 First Class Carriage.	3 Composite, First and Second Class.	4 Composite, First, Second, and Third	5 Composite, Second and Third.	6 Third Class Carriage.	7 Fourth Class Carriage.	8 Five Ton Wagon.	9 Ten Ton Wagon.	10 Axles of Iron.	11 Axles of Steel.	12 Tires of Iron.	13 Tires of Steel.	14 Wheels: Spoke.	15 Wheels: Disc.	16 Sleepers.	17 Rails per Mile of Perm. Way.
	£.	£. s.	£. s.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s.	£. s.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	d.	£.
Cologne-Minden .	117	..	7 1	6 4 6	6 4 6	2 13 6	2 13 6	1 8	1 12	1 5	1 3	5 9	6 9	3 9	1 1	1·8	62
Bergish-Maerkish	124	..	22 10	22 10 0	21 15 0	18 10 0	16 15 0	5 14	6 18	..	..	..	..	..	..	1·8	66
Rhenish . . .	154	24 10	23 5	..	20 0 0	17 0 0	16 0 0	7 10	11 0	..	..	..	..	..	..	2·88	50

TABLE M.—EXPERIENCE of the WEAR of TIRES on the COLOGNE-MINDEN RAILWAY, from 1845 to 1863, reduced to a Diameter of 5 Feet and a Weight of 10 Tons on each Axle, the Wear calculated in the inverse ratio of the Diameter and the direct ratio of the Load.

DESCRIPTION.	Wear of Driving-Wheel Tires.						Wear of Running-Wheel Tires.						Wear of Tender-Wheel Tires.			
	1 Borsig's Iron.	2 Low Moor Iron.	3 German Iron.	4 Puddled Steel.	5 Krupp's Steel.	6 Bochum Steel.	7 Borsig's Iron.	8 Low Moor Iron.	9 German Iron.	10 Puddled Steel.	11 Krupp's Steel.	12 Bochum Steel.	13 Borsig's Iron.	14 Low Moor Iron.	15 German Iron.	16 Puddled Steel.
Miles till first turning .	15,190	11,810	12,170	13,570	19,980	30,890	15,210	9,980	9,520	11,560	22,730	25,620	18,160	15,880	15,940	15,160
Miles till final wear .	39,710	29,820	27,590	37,495	61,820	..	49,580	46,250	29,690	43,530	67,100	..	54,550	27,300	34,420	48,500

TABLE N.—EXPERIENCE of the WEAR of TIRES on the COLOGNE-MINDEN RAILWAY, from 1845 to 1863, taken from the Effective Mileage, irrespective of Quality of Material and Diameter.

DESCRIPTION.	1 Driving-Wheel Tires.	2 Coupled-Driver Tires.	3 Running-Wheel Tires.	4 Leading-Wheel Tires.	5 Trailing-Wheel Tires.	6 Tender Tires.
Miles till first turning. . . .	12,292	11,762	..	12,656	17,843	22,360
Miles till final wear . . .	33,218	30,340	46,220	..	..	69,684

TABLE O.—PERFORMANCE and WEAR of CARRIAGE and WAGON TIRES on
18,458 Puddled-Steel, and

NAME OF MANUFACTURE.	1 Material.	2 Diameter inside.	3 Thickness.	4 Weight on each Tire.	5 Till 1st Turning. Distance run.	6 Wear.	7 Distance run for every 1/10 Inch.
		Inches.	Inches.	Cwt.	Miles.	1/10 In.	Miles.
Bochum Company.	Cast-Steel, on Steel disc.	36	2	72	81,695	1·82	44,887
Ditto . . .	Cast-Steel, on Iron disc.	37½	2	72	70,714	1·52	46,522
Krupp . . .	Cast-Steel, on Iron disc, without break.	35¾	1⅛	72	47,807	1·4	33,434
Hoerder Works	Puddled-Steel, on Iron disc.	35¾	2	72	24,807	1·9	13,056
Ditto . . .	Puddled-Steel, on Iron disc.	35¾	2	40	53,527	2·45	21,845
Various German Works.	Iron, on Iron disc.	35¾	2	72	17,522	1·74	10,100
Ditto . . .	Iron, on Iron disc.	35¾	2	40	23,723	1·88	12,619

NAME OF MANUFACTURE.	1 Material.	2 Diameter inside.	3 Thickness.	4 Weight on each Tire.	17 From 4th to 5th Turning. Distance run.	18 Wear.	19 Distance run for every 1/10 Inch.
		Inches.	Inches.	Cwt.	Miles.	1/10 In.	Miles.
Bochum Company.	Cast-Steel, on Steel disc.	36	2	72	..	..	..
Ditto . . .	Cast-Steel, on Iron disc.	37½	2	72	21,451	1·33	16,128
Krupp . . .	Cast-Steel, on Iron disc, without break.	35¾	1⅛	72	8,336	0·66	12,621
Hoerder Works	Puddled-Steel, on Iron disc.	35¾	2	72	7,166	1·38	5,192
Ditto . . .	Puddled-Steel, on Iron disc.	35¾	2	40	21,479	1·8	11,933
Various German Works.	Iron, on Iron disc.	35¾	2	72	8,963	1·46	6,138
Ditto . . .	Iron, on Iron disc.	35¾	2	40	..	..	..

Cologne-Minden Railway, taken from the average of 3,046 Cast-Steel, 4,086 Iron Tires.

8	9	10	11	12	13	14	15	16
From 1st to 2nd Turning.			From 2nd to 3rd Turning.			From 3rd to 4th Turning.		
Distance run.	Wear.	Distance run for every 1/10 Inch.	Distance run.	Wear.	Distance run for every 1/10 Inch.	Distance run.	Wear.	Distance run for every 1/10 Inch.
Miles.	1/10 In.	Miles.	Miles.	1/10 In.	Miles.	Miles.	1/10 In.	Miles.
73,339	1·82	40,926	40,772	1·33	30,656	(running	after	195,806 miles.)
74,983	1·75	42,846	54,622	1·8	30,345	66,811	1·33	50,234
60,651	1·2	50,542	36,766	1·66	22,148	41,601	1·46	28,493
17,380	1·66	10,470	9,810	1·43	6,860	9,230	1·46	6,322
24,470	1·88	13,016	31,406	1·97	15,990	19,148	1·56	12,274
12,951	1·53	8,458	13,339	1·56	8,551	11,355	1·36	8,350
12,133	1·41	8,598	34,758	2·1	16,552	31,298	1·88	16,647

20	21	22	23	24	25	26	27	28
From 5th to 6th Turning.			From 6th to 7th Turning.			From 7th to 8th Turning.		
Distance run.	Wear.	Distance run for every 1/10 Inch.	Distance run.	Wear.	Distance run for every 1/10 Inch.	Distance run.	Wear.	Distance run for every 1/10 Inch.
Miles.	1/10 In.	Miles.	Miles.	1/10 In.	Miles.	Miles.	1/10 In.	Miles.
..	..	..	..	..	..	..	..	..
(running	after	288,581	miles.)	..	..	..	..	..
(end of	life.)	..	..	..	..	..	..	..
8,233	1·4	5,880	7,966	1·36	5,858	4,924	1·33	3,702
20,983	1·66	12,640	10,213	1·33	7,686	..	..	..
5,166	1·33	3,864	4,231	1·0	4,231	..	..	..
..	..	..	..	..	..	..	..	..

TABLE O, *continued*.—PERFORMANCE and WEAR of CARRIAGE and WAGON TIRES on COLOGNE-MINDEN RAILWAY, taken from the Average of 3,046 Cast-Steel, 18,458 Puddled-Steel, and 4,086 Iron Tires.

TOTAL.

NAME OF MANUFACTURE.	Material.	Diameter.	Thickness.	29 End of Life. Total Distance run.	Weight on every Tire.	30 Distance run for every 1/10 Inch.
		Inches.	Inches.	Miles.	Cwt.	Miles.
Bochum Company.	Cast-Steel, on Steel disc.	36	2	..	72	39,398
Ditto . . .	Cast-Steel, on Iron disc.	37½	2	..	72	42,880
Krupp . . .	Cast-Steel, without break.	35¾	1⅛	195,161	72	30,588
Hoerder Works	Puddled-Steel.	35¾	2	89,516	72	7,508
Ditto . . .	Puddled-Steel.	35¾	2	188,912	40	14,934
Various German Works.	Iron.	35¾	2	73,507	72	7,365
Ditto . . .	Iron.	35¾	2	101,912	40	14,018

[Mr. ROCHUSSEN

Mr. ROCHUSSEN, in elucidation of the Tables, said he had inserted a greater number of details, especially with regard to wheels, than would have been necessary if he had been dealing with rolling stock constructed in England. He had given the number of stations, showing that there was a station at about every 4¾ miles. Most of the trains on the Prussian lines were of the omnibus class, therefore the breaks were often used; and that was the special work thrown upon the tire. It was the rule of the Prussian Board of Trade, that every fifth wheel must have a break; but on the southern sections of the Cologne-Minden and Bergish Maerkish railways, where the inclines were steep, there was a break to every wheel.

He had abstracted the weight of the rails in order to explain that, on those railways, short lengths of iron permanent way had been tried experimentally, and hitherto with complete success; but as the trial had only extended over a year and a half, it would hardly be fair to bring the results before the public at present. The general features of the permanent way were, two angle irons, 6½ inches high, by 5½ inches wide, with a steel head between, held down by a key, which joined the two angle-irons together, and forced the steel head down. That arrangement gave a base of 12 inches; and the two flanges of the angle-iron stood at an angle of 7°. The boldest experiment was that made on the Rhenish line; and certainly the contrivance seemed rather crude: the rails were 12 inches deep, with steel tops, the base was 9 inches wide, the weight was 195 lbs. to the yard, and the rails were laid on the ballast.

Table B was intended to describe the rolling stock itself; and in that, the average results of the running wheels of the engines were given. In Germany, there was seldom any distinction made between the trailing and the leading wheels; and the running was described indiscriminately, except where the work was separated. The item was, distance run when working at a profit. If, for instance, a train from London Bridge to Croydon took a pilot-engine to go from New Cross to Norwood, that engine would get credit for a run of 5 miles; but when returning without a train, the 8 miles to London Bridge would not be credited to it except in the ultimate mileage: so that those Tables had the disadvantage of being framed in contradistinction to what was done in England; no loss was assumed at any station, but in the work done by the engines, he had expressed simply that particular work, as in Table C, col. 6. For every hour of steam at a station he had taken an average of 5 miles' work done. That was to show the effect of the frequent use of the breaks upon the tires. Every station implied the use of the breaks. In Table D, col. 5, where the total cost of the profit mile for working the engine was put down at 9·29*d.*, and in Table K, col. 23, where the expense of the engine per train mile was given at 44·2*d.*, the one applied to the motive power, the other to the actual cost of the train. In Table K, col. 23, the heading was expenses per engine per mile, and the amount given, viz. 44·2*d.*, meant per engine-profit mile,—*i.e.* while the engine was earning money. He must remark that, in addition to column 13, Table C, where the average number of axles in a train was stated, the net load on each was an average of 73 cwt. In the results of Table B, the salaries of the whole of that department were included. The same remark applied to repairs and renewals, which comprised expenses of workshops, tools, &c. The items of oil, tallow, and cleaning were to be found in column 4 of Table D. On the Prussian railways, the cleaning was done by a separate staff; and on the Cologne-Minden it was done by contract, and cost, on an average, 1*s.* 10½*d.* per engine.

Table E referred to the repairs and renewals of engine tires. The figures in columns 2, 3, and 4 would probably appear high; the 115 per cent. did not, however, represent the ratio of those repairs, but simply the fact, that that number of tires wanted some repairs; and that was corroborated by Table M, which showed the average of years. In speaking of the wear of tires, it was necessary to state that the weight of the passenger-carriages, when empty, was about 9½ tons, which, compared with the weight of the carriages used in England, was an additional evidence in favour of those tires.

Table K was added to make the framework of the Paper rather more complete. The fares, as there indicated, were very low, and would be lower still; for, on the Belgian State system, the railway fares would be further reduced by a little more than ⅖ths; and as the Belgian system was connected indirectly with two, and directly with one of those lines, an arrangement was in course of organization by which the fares on all the lines would be reduced in some degree, if not to the same extent. The dividend of the Cologne-Minden Company was 15⅚ths per cent. By their charter they were limited to 20 per cent. The Prussian Government guaranteed 4 per cent. upon the ordinary stock; but stipulated that if more than 15 per cent. were earned, the surplus was to go as a bonus to the Government. The Cologne-Minden reserved something for every component part of the carriage, whereas, on the other lines, the reserve was a certain sum for every carriage, including all its working parts.

In Table M, the results given were those rather of calculation than of observation. There were so many different diameters of wheels, that one wheel could scarcely be compared with another, unless the wear and tear of each, as compared with its diameter, were taken into consideration, and therefore it was resolved to take the diameter of 5 feet as the standard, which reduced the wear of the tire of a 6-feet wheel running 12,000 miles till its first turning, to the wear of the same tire on a 5-feet wheel running 10,000 miles. Taking 10 tons as the load on each axle, the wear would be in the ratio of the weight upon the axles. He had accompanied this Table by another, N, which gave the average performances of all the tires, irrespective of the material, whether of puddled steel or of iron.

Of all the Tables, O might be termed the most essential, as embodying information drawn from a large number of tires. It gave every stage of turning, the distances run from one stage to another, and the thickness of steel or iron worn off, and also the distance which every $\frac{1}{16}$th of an inch of material represented. In the two latter instances, the Bochum Company's cast steel tires showed excellent results—the one, running on a steel disc wheel, being in good condition after 195,000 miles run; the other, on an iron disc, having run 288,000 miles. Column 3, in this Table, showed the effect of the use of fibrous iron in giving elasticity with steel, and that of a steel disc; and the result was 39,000 miles in the latter case, as against 42,000 miles in the former.

He wished particularly to direct attention to the favourable results shown by puddled steel and iron tires under the lighter weights. Those, with 40 cwt. on each axle, had about double the wear of tires loaded with 72 cwt. on each axle. That fact might be of greater value, from the circumstance that few English axles were required to bear more than the lighter weights given in the above Table.

As to grinding the tires, he would remark that it obviated the necessity of taking a deep bite with the tool in the lathe, by which much material was wasted. At present the workmen had to regulate his template to keep the circular form; but in an improved grinding apparatus there was a contrivance by which that plate acted on the grinding bench as a check; and when the tire was finished, the whole contrivance threw itself out of gear.

Mr. G. P. BIDDER, Past-President, was sure that all would concur in thanking the Author for having added so much to their statistical knowledge on matters connected with their practice as railway engineers. He thought great advance had been made in the character of the statistics presented to the Institution; and in venturing to suggest what he considered was necessary to perfect that information, he wished to be understood as not underrating in the slightest degree the great labours of the Author, or those of Mr. Williams, in the Paper which immediately preceded the present one.[1]

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[1] *Vide ante*, page 353

The Author had pointed out that on the Prussian railways nearly all the trains were what in England were called 'omnibus trains,' stopping at all, or at most of the stations, and were therefore subject to extra break power in arresting their progress. Now, he inferred from that statement, that the trains did not travel at the extreme speed to which the public were accustomed on most of the great lines in this country.

With regard to the wear of rolling stock and rails, he thought both were subject to three elements; there was the effect of time, of weight, and of speed. The statistics, therefore, though extremely valuable, must be and must remain imperfect till some means were adopted of eliminating each of those elements. He was prepared to subscribe to the opinion that the wear of the rails on a road was as the square of the speed of the trains, and he believed that was capable of demonstration upon the simplest principles; but there were other elements which aggravated the destruction, beyond simply the squares of the velocities.

In all those things it was necessary to recur to the commercial consideration of annual repairs and renewals. No Engineer would desire, if he could help it, to have anything else than the most perfect road that money could command; but the difficulty had always been in inducing Directors to incur the expense of providing the best materials; and after valleys had been filled up, hills cut through, and viaducts erected, that which was the crowning work of the whole—the permanent way—was often put together with the least degree of care.

With regard to permanent way, undoubtedly those three elements came into play—in the first place, the simple element of time, told upon the sleepers. Then the element of the weight of trains indirectly affected the sleepers and directly affected the rails; and lastly, hastening the destruction of both, came into play the effect of extreme speeds. Therefore in the application of creosoted sleepers and steel rails in their commercial bearing, not one of those elements should be neglected. With regard to the wear of the rails, particularly if near a station, like that of Derby, or Camden Town, and other places where the life of an ordinary rail was only from two to three years, the application of steel was of most unquestionable benefit; but with the ordinary traffic of railways, such as that on many of the branch lines, of four or five trains per day, and those running at low velocities, it was doubtful whether steel rails at £12 per ton, or £13 per ton should be applied. On an ordinary railway, and under ordinary work and circumstances, an iron rail might be calculated to last fourteen years. Then the question was, whether it was desirable to adopt the steel, or the ordinary rail? He assumed, that steel rails could be supplied at £12 per ton, while ordinary rails would cost £8 per ton. In that case there would be £4 left as the difference in the price. He assumed that a steel rail would last three times an ordinary rail. The result at the end of 14 years would be this, —The iron rail was worn out; but there were £4 in hand, which by the process of compound interest at 5 per cent. represented £8, and further, there were the old rails, which were worth £4 per ton; and thus with new rails and £4 in hand at the end of that period, a fresh commencement could be made, and that process might go on *ad infinitum*. When steel rails at £12 per ton, at the end of the 42 years had to be replaced, there would be no balance in hand, £12 being the price of the steel rails; the old rails might be disposed of at £8, but then £4 had to be found, so that there was a loss of £4 in the one case against a profit of £4 in the other case. Taking that then as the starting-point, if the traffic was such as would not prevent ordinary rails lasting 14 years, he did not see the advantage of applying steel; but for traffic which would wear them out in less than 14 years, steel rails would be the proper thing. With regard to sleepers, there was considerable discrepancy of opinion. The life of a creosoted sleeper had, on the one hand, been estimated at, he knew not how many years, while on the other hand, it had been stated that Baltic sleepers 9½ inches by 4¾ inches could be bought at 2*s*. 4*d*. or 2*s*. 8*d*. each, and that those sleepers, unprepared, lasted for 16 years. The former part of the statement surprised him, though he did not doubt its correctness; but he must add, that the practice of using creosoted sleepers, was, if judiciously applied, one to which he was prepared to give his assent.

Mr. F. J. Bramwell said his acquaintance with the subject of railway wheel-making was of early date. He was engaged in that manufacture at a time when there was not a single line of railway into London, and when the only evidence that such a thing was about to be, was a board near where the St. Thomas's Hospital once stood, on which was written "Greenwich Railway."

The Author of the Paper was clearly in favour of disc wheels. It was indeed difficult to say why disc wheels were not received in this country. The only valid objection he had ever heard urged against them was their noise. He really believed the true source of the amount of disfavour those wheels had met with, was the absence of the supposed beauty of form which existed in the ordinary spoke-wheel. That in bygone days the beauty of form influenced the engineering mind, was undoubted; and as a proof of this he might state, that those wheels which were brought forward some twenty years ago, and which were made with semicircular spokes, had a great run, because of their appearance; and this was maintained notwithstanding that the spokes cracked (as of necessity they must) through the rivet-holes. The disc wheel, spoken of in the Paper, appealed to the judgment of Engineers as being correct; and so long ago as the year (he believed) 1836, before the opening of the Blackwall Railway, he was engaged under the late Mr. Hague, in the manufacture of wrought-iron disc wheels. In those wheels the discs were cast into the bosses, and were in each wheel riveted to a pair of angle-irons, and the tires were riveted upon those pairs. That was much the same as the wheel shown in one of the diagrams, except that Mr. Hague's wheels had double discs instead of single ones. He never heard any objection made to those wheels, except as to their ugliness: but that was fatal; and on this ground they were a commercial failure.

So much for disc wheels in former years in England. It was well known that in America, for the large passenger-cars on eight wheels, cast-iron wheels were used as a rule—the tires being of cast iron as well as the other parts; and the disc form for those wheels was almost universal. Corrugation was given to the discs, not so much with a view to obtaining elasticity when the wheel was at work, as to prevent risk in the contraction of the casting.

Of late years the wooden disc wheels had been somewhat extensively used in England, and he believed in every case they had given great satisfaction. He must again be allowed to express his approval of the disc form, as from its use there was uniformity of support given to the tire, and, therefore, great probability of the tire being worn equally, instead of wearing into a succession of hollows, which frequently occurred when the support was given by spokes; and when once that uneven mode of wearing was set up, the destruction of the wheel was rapid, and brought with it a corresponding amount of destruction to the rails. Another advantage of the disc form was the prevention of the cloud of dust that was given off at the level of the boss of a wheel having spokes, when a train was suddenly brought to rest at a station. That dust must have an injurious effect in cutting out the journals and brasses, as it was flying about at the very time the axle-boxes were being opened to receive grease. He thought that, on the ground of uniform support to the tire, and on that of freedom from dust, the disc form of wheel was commendable.

From the ability displayed in the Paper, he had but little doubt that the grinding apparatus to which allusion had been made would be found to be well designed for its purpose: but although that particular implement might be novel, the grinding of tires, *per se*, was not a new thing. In 1840, he was engaged in the manufacture of wheels which had steel tires. That was a tire compounded of steel and iron; the steel being laid upon the iron in the pile, so that, when the tire was rolled, it was formed with a face of steel and a back of iron. In cases where those tires were put upon wooden wheels, it was necessary to quench them. That, of course, hardened the wheel surface so that it could not be turned. As a remedy, the tires had been made with a very thin skin of iron above the steel, the object being to protect the latter metal from the water, so as to leave it in a condition capable of being turned after quenching; but the plan had not succeeded, because it was not possible to get the iron of uniform thickness, and thus the surface of the wheel, after turning, was varied in hardness. The former system of steel face without an iron covering was reverted to, and the tires were completely turned before being put on the wheels and quenched; but after that process the result was somewhat irregular. That irregularity was remedied by grinding, performed by putting on a slide rest a grindstone revolving at a very high velocity, while the wheel to be ground revolved slowly in an opposite direction, and thus a result was obtained which could not be effected by the turning tool. The grinding process, however, he had found an expensive one; and it was questionable whether that mode of manufacture would pay. It had been shown that the German railways which adopted that system made far larger profits than the English lines, although the fares were lower; but, although that was evidence of general good management, it did not serve to clear up the doubts which might arise in relation to individual instances.

Until disproved by the actual figures, he should doubt whether a better tire, viewed commercially, could not be obtained either by turning or by the system of endless rolling. He had seen, with great admiration, the contrivance used in the figure called 'the new system,' for getting over the difficulty, and alluded to by the Author, of the unnecessary use of a costly material. No doubt many present had seen the specimens of Bochum steel wheels that were shown by Messrs. Naylor and Vickers in the Exhibition of 1862; but those had the same expensive material in the body of the wheel as in the tire. He could well understand how natural it would be to endeavour to save this cost by putting a cheaper material into the wheel centres, but he should have feared that, however desirable it might be to do so, every one would be deterred by the difficulty of making the weld, and he was much struck with the good workmanship which must obtain to enable a sound and efficient weld to be made between a fibrous iron centre and a steel tire, in the way shown in the drawing. Those who had the ability to carry out such workmanship, deserved every praise at the hands of practical workers in iron.

If he were in order, he wished, as bearing on the subject, to allude to some wheels of French invention, which were then being made in England. Those were spoke-wheels, but manufactured in a way different to the ordinary one, viz., by one blow of a hammer. That was effected by laying together the boss, the spokes, and the inner rim, in separate pieces, in the form desired when the wheel was finished: those were put into a furnace large enough to receive them, when placed together in the form of a wheel, were heated to a welding heat, and then taken out in a clip and put into a bottom die made to the figure of the finished wheel; and then a top die of a similar figure came down, with a force due to a fall of 4 or 5 feet, and a weight of some 10 tons, and by that one blow all the parts of the wheel were absolutely welded together and completed of the true shape, except a little surplus metal which exuded at the junction of the dies, and that was trimmed off when the wheel was removed from the dies.

There was another kind of wheel manufactured in England, which was also a foreign invention: it was a very ingenious, though simple thing. There were in common use in England wrought-iron spokes, cast into a cast-iron boss, and also wheels formed entirely of wrought iron, in which the spokes and the boss were welded together, either by the old hand-process, or by the plan he had just described; but those wheels solidly welded together were, even when done by machinery, very expensive; while the cheaper mode, that of casting into the boss, was, to a certain extent, unsatisfactory. There was always a fear that the metal of the boss might be blown; and to lessen the chance of this, bosses had been made of dimensions far greater than was needed if the casting were sound; that was to say, for a railway wheel 2 feet 9 inches diameter, a cast-iron boss of 13 inches diameter and 7 inches thick, was not unfrequently used; that was a useless lump of cast iron, employed only with the object of preventing splitting in the contraction of the metal.

The second foreign invention of which he wished to speak was devised with the view of making a wheel which, although perhaps not quite equal to the welded wrought wheel, should be far superior to that of having the spokes cast into the boss. The plan pursued was, to place together the spokes in the required form, to heat them to a red heat, and to lay them on the lower half of a wrought boss at a welding heat; then to take the other half of the wrought-iron boss, also at a welding heat, and place it on the spokes, and by a powerful blow bring the top and bottom parts of the boss together. Those parts became welded, the one to the other, and the spokes cut their way into the plastic mass of the boss, and thus there was produced a wrought-iron boss to closely grasp the spokes, instead of a cast-iron boss; and that could be done at a cost little if anything above that of a cast-iron one. The reason that that mode of manufacture was so much cheaper than that in which the spokes were really welded to the boss, was, that if the spokes were brought to a welding heat, it was necessary to form them of special rolled iron, or of forgings, to provide for the waste that took place on getting them to a welding heat; but when a red heat only was given to the spokes, this waste did not arise, and therefore the ordinary flat bar could be used for those spokes, in the same way as it was used when the spokes were cast into the boss.

The wear of wheels consequent upon the action of the breaks had been alluded to, and it had been pointed out how much the wear was increased by the frequency of stoppages at stations. In his opinion, the injurious effects of breaks were much aggravated, in England at all events, from putting too good work into them. In a break-carriage, or in a tender having two pairs of wheels, there was usually a shaft, working accurately in its bearing, and having a lever upwards and another lever downwards; from those levers, rods extended which worked the break block; those rods had contrivances to alter their lengths, and it was sought by those means to adjust the blocks so that all should bear upon the wheels; but as a matter of fact, that end was not attained. He had, for some years past, made it his business to watch the break-carriages as they arrived, and he had no hesitation in stating, that if the carriage had two pairs of wheels, in three cases out of four one pair was stopped while the other pair continued to run; while if it had three pairs, it was rare indeed that one of those pairs did not continue to run, and more commonly two out of the three continued to do so. That of course arose from the impossibility of adjusting the blocks correctly. It might be asked, why was it so necessary to adjust the blocks correctly in the first instance, since the block which was prominent must soon be ground down so as to come to its bearing? But that opinion, although commonly entertained, was, in his judgment, an erroneous one, as the prominent block seized the wheel, and prevented its further rotation; while the non-prominent block, although not near enough to stop the wheel, was near enough to be ground away, and thus always remained away from its work. All this difficulty, however, would be obviated if the work were done a little less well; that was, if instead of making a truly fitting hole for the shaft, Engineers would be content to put the shaft into a slotted hole, so that it might shift a little, just so much as would insure that the break-block on one pair of wheels should be the abutment for the other block, instead of leaving the bearing of the axle to become that abutment. That was done in America: there, the large eight-wheeled cars had a break-block to each wheel, and yet each block was made an abutment for the other, so that it was impossible to break one wheel with more or less power than another.

Both on the ground of safety to the train, and on that of the wear of the wheels and rails, the proper action of the breaks was a most important subject, and he could not help fearing that, in this country, it was the constant practice to expend a large sum in the construction of breaks, and then to succeed only in obtaining a bad result; while in America, a cheap but judicious construction obtained a far better result, and he thought this unsatisfactory condition of things arose from the subject not having met with due consideration.

Mr. G. H. PHIPPS remarked, that of late years much had been said on the importance of giving elasticity to railway wheels. That object had been attained in engine wheels by means of steel springs inserted between the felloe and the running tire. The disc wheel now under discussion seemed to be wanting in the property of elasticity, and he would expect to find it very harsh and unyielding. No doubt the curvature of the transverse disc did afford some small proportion of elasticity; but in proportion as the disc wheel was harsh and unyielding, the successful use of it militated against the views he had just alluded to.

Mr. C. H. GREGORY, V.P., thought the information they had before them, on the wear of the tires of disc wheels, would have been more useful if it had been supplemented by comparative observations upon the wear of tires on ordinary wheels under similar circumstances. A disc wheel of iron suggested to most minds the idea of rigidity, and he believed that there would be difficulty in getting out of a disc wheel the amount of elasticity which he liked to see in a wheel, without making it unduly weak; and while most people admitted the advantage of hardness of surface both for tires and rails, he thought it was generally agreed that there was some advantage in not having too much rigidity, either in wheels or permanent way. The statements which had been laid before the Institution, of the results of placing a spring between the tires and the rims of wheels, seemed to show, that elasticity produced a satisfactory result in regard to wear; but if it could be shown that the disc wheel possessed advantages over the spoke wheel, the inference might be that they would do well to return to the old form of wheel with a cast-iron boss, which approached more nearly to a disc wheel than the modern type with a wrought-iron boss.

Incidentally to the question of rigidity, he considered that the permanent way alluded to by Mr. Rochussen, in his verbal observations, in which the metal was of very deep section, and weighed as much as 195 lbs. to the yard, must of necessity be very rigid, and that it was not likely to be a good running road. In a commercial point of view it had this obvious disadvantage, that when the surface was worn out, they would have to replace metals of great weight instead of from 60 lbs. to 80 lbs. to the yard, or less.

With regard to the American disc wheels, their introduction was one of the many instances in which the institutions of that country had been adapted to its wants. In those parts of North America where the railway system was first largely developed the extremes of climate were said to have had an injurious effect upon the ordinary wheel first used—a wheel with a wrought-iron skeleton and a cast-iron boss, and the trial of one summer and one winter reduced them to a dangerous condition. The American Engineers met this difficulty by adopting a cast-iron disc wheel, of the charcoal iron of the country, which was of very good quality. He had seen some corrugated discs in cast iron resembling the wrought-iron wheels of which the Author had exhibited diagrams, but the most usual form had two dished discs, separate at the boss and meeting at the rim, cast with a core afterwards drawn out through holes in the discs, the tire being cast in a chill, in one piece with the wheel. He was surprised to hear how rarely these wheels failed in America—how well they stood their work—and their long life; still they seemed to him to run hard, and he thought they could not be good for the permanent way.

Having called attention to the necessity for having comparative statistics of the wear of different wheels under similar circumstances, he would add that the effect of the wheel upon the rail should not be lost sight of, and that in considering the merits of a strong permanent way or a strong wheel, they should endeavour to ascertain what would be the effect of either upon the other; so that durability in one part of the system might not be sought at the expense of short life in another part.

Mr. Rochussen considered the defects of the American cast-iron wheels were heating under the break, and brittleness when passing through snow or a pool of water. As to the combination of that iron by welding, the great advantage of a 'wheel so made was its elasticity, and the whole secret was, that when the tire was run down to an inch, or three-quarters of an inch, its elasticity became complete from the vibration running through the wheel. With respect to the combination of the wrought-iron disc and welded tire, that wheel was attempted to be worked in Belgium, but it was found to be faulty, owing to the clumsy method of forming the disc. The great advantage of manufacturing by rolling instead of stamping was, that by continual rolling the wheel became elastic, while by stamping, all the rigidity was produced which it was desired to avoid.

No. 1,153.—"On the Results of a series of Observations on the Flow of Water off the ground in the Woodburn District, near Carrickfergus, Ireland; with Rain-gauge Registries in the same locality, for a period of twelve months, ending 30th June, 1865."

By Robert Manning, M. Inst. C.E.

For the last fourteen years the water supply of Belfast has been very insufficient, and every available source has been reported upon and discussed. Finally, during the last Session of Parliament an Act was obtained empowering the execution of a plan for procuring water from near Carrickfergus, and of this scheme, the Woodburn rivers formed a considerable part. The Author was engaged, during the progress of the Bill, by one of the principal proprietors of water-rights on those rivers, and found it necessary to make frequent gaugings of the flow off the ground, and to register the rainfall of the district. Being aware of the utility of such observations to hydraulic Engineers, and that the Council of this Institution had, for some years past, invited communications on the subject, he continued the observations after the immediate necessity for doing so had ceased, and he now begs leave to submit the results to the notice of the Members.

It is not intended either to give a description of the proposed supply to Belfast, or to examine from a meteorological point of view, the data collected; but merely to report the facts accurately, and to draw attention to such results as appear to be of practical moment.

In Plate 24 are shown the courses of the two branches of the Woodburn river, and the extent of the rain basin; the elevation varies from 500 to 1,000 feet. The surface is chiefly composed of bare mountain pasture and grazing land, the upper rock being almost entirely tabular trap, overlying the chalk, with here and there patches of green sand.

Three gauges were placed respectively 300 feet, 750 feet, and 900 feet above the level of the sea, at the points marked on the plan; and two stream gauges were erected, one on each branch of the stream, the positions of which are also indicated. The receiver of each rain gauge was placed about 2 feet above the surface, and was 10 inches in diameter; the body of the gauge was of the same size, and from a float within it, the observations were made by a rod divided into inches and tenths. The stream gauges were rectangular notches with sharp edges, such as were used by

Mr. Francis, in his well-known experiments at Lowell, and the formula for calculating the discharge was

$$Q = 200\,(L - 0.1\,n\,H)\,H^{\frac{3}{2}}$$

where

Q = the quantity of cubic feet per minute,
L = the length of the notch in feet,
H = the head in feet,
and
n = the number of end contractions.[1]

When the notch is the full width of the stream, $n = 0$, and the formula is simply

$$Q = 200\,L\,\sqrt{H^3}.$$

differing from that in general use only in the coefficient, which is 7 per cent. less. It was employed in the present case in order to avoid all risk of exaggeration.

The notch on the southern branch of the stream received the drainage of 2,076 acres; that on the northern branch of 1,329 acres. Daily observations were taken at both, for the year ending June 30th, 1865; and weekly observations were made of the rainfall at all the three gauges before described. The rain gauge at Queen's College, Belfast, nine miles south of the district, where a daily registry had been kept for fourteen years, was used as a standard.[2] A summary of the results is given in Table No. 1, page 460.

The main facts thus collected are as follows:—The rainfall for the twelve months ending June 30th, 1865, was 35·867 inches, being nearly 18 per cent. above the rainfall at Belfast, which was only 30·5 inches. For the six months from November to May, the rain and the flow were respectively 14·766 inches, and 14·351 inches; the flow in December and January exceeding the rain by 0·927 inch. From May to November these quantities were 21·101 inches and 7·357 inches; the total loss on the year's rain being 14·159 inches. The minimum flow off 1,000 acres occurred in August, and amounted to 11 cubic feet per minute; the maximum was in September, and was as high as 3,180 cubic feet per minute. The mean monthly flow was at its minimum in July, and was 29 cubic feet per minute, attaining its maximum in November, when it was ten times that quantity. The year's rainfall, at an elevation of 900 feet, was 35·9 inches, at 750 feet it was 36·3 inches, and at 300 feet it was 35·4 inches.

These particulars having been ascertained, it was assumed that

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[1] For a full explanation of this formula, *vide* "Lowell Hydraulic Experiments," by J. B. Francis. 4to. Boston, 1855.

[2] The observations, nearly 800 in number, may be consulted at the Institution.

TABLE No. 1.

MONTHS.	Rainfall.					Run off.	Loss.	Mean Monthly Flow off 1,000 Acres in Cubic Feet per Minute.
	Queen's College.	Woodburn.						
	65 ft.	900 ft.	750 ft.	300 ft.	Average.			
1864.								
July . .	1·650	1·9	1·8	1·8	1·833	0·361	1·472	29·58
August .	2·396	4·2	4·6	4·4	4·400	0·531	3·869	43·86
September	2·526	4·5	4·6	4·6	4·567	2·551	2·016	214.428
October .	3·370	5·0	5·1	4·5	4·867	2·412	2·455	197.394
November.	3·606	3·9	3·9	4·1	3·967	3·460	0·507	291·582
December.	1·586	2·3	2·5	1·9	2·233	2·712	+·479	221·442
1865.								
January .	4·147	2·7	2·4	3·2	2·767	3·215	+·448	261·522
February .	3·001	2·7	2·9	2·6	2·733	2·312	0·421	238·476
March . .	2·879	2·1	2·2	2·7	2·333	2·184	0·149	178·356
April . .	0·461	0·9	0·7	0·6	0·733	0·468	0·265	39·78
May . .	3·914	4·0	4·0	3·6	3·867	1·103	2·764	90·180
June . .	0·964	1·7	1·6	1·4	1·567	0·399	1·168	33·66
	30·500	35·9	36·3	35·4	35·867	21·708	14·159	
Winter .	15·680	..	..	..	14·766	14·351	0·415	1st Nov. to 1st May.
Summer .	14·820	..	..	..	21·101	7·357	13·744	1st May to 1st Nov.

the rainfall on the Carrickfergus mountains bore a constant ratio to that at Belfast. The exact proportion for the year 1864-5 was 1,176 to 1,000; but the same care was taken to avoid exaggeration in this instance, as in the calculation of the flow off the ground, and it was assumed to be only 16 per cent. greater than was given by the gauge at the Queen's College. The following are some of the results:—

Maximum rainfall, 1852	47·71 inches.
Mean rainfall for fourteen years, 1851 to 1864	38·42 inches.
Average of the three dry years, 1855-6-7	32·76 inches.
Minimum year's rainfall, 1855 . .	28·80 inches.

The question still, however, remains to be answered, how much of this rainfall is available for water supply?

Twenty or thirty years ago, the evaporation was taken as proportional to the rainfall, and was variously estimated at one-sixth, one-third, and two-thirds of the mean annual rain, according to circumstances. At the present day the balance of opinion seems to be that the amount of evaporation is not proportional to the rainfall; that it is either constant, or within narrow limits, where there is an identity, or similarity, in the physical features of the districts compared; that it varies under different circumstances in this kingdom from 9 inches to 19 inches; and that the estimated amount for any particular case, must be left to the experience and judgment of the Engineer.

Many of the apparent differences of opinion on this subject have arisen from a loose manner of using the word 'evaporation;' for while it is by some intended to express the total evaporative force, with others it means 'the loss,' or difference between the rainfall and the supply, which is the resultant fact of greatest practical value. That the 'loss' cannot be constant, but will depend in a great measure upon the distribution of the rain, will be obvious from the consideration, that two years of precisely the same rainfall will give, for the same district, a very different supply, if in the one there be a wet summer, and in the other a wet winter. It will in some cases occur that there will be a gain, so to speak, instead of a loss, as in the instance before mentioned, of the months of December and January. And if there be one or two months in summer of absolutely dry weather, it is possible that the loss on the year may be less, by from 3 inches to 6 inches, than if heavy rain had fallen.

From this, and from similar considerations, the mean loss in the Woodburn district, was calculated in the following manner:—The records for the year 1864-5, showed, that for the six months from November to May, the actual loss amounted only to 0·415 inch, while from May to November it was 13·744 inches. For the first period it never exceeded ½ an inch in a month; for the second it varied from 1 inch to nearly 4 inches in the same time. For the three months, November, December, and January, the average loss was taken at 0·20 inch; for February, March, and April at 0·40 inch; for May, June, and July at 2 inches; and for August, September, and October at 2·80 inches. The minimum flow of the streams was taken for the six winter months at 0·8 inch per month, and for the six summer months at 0·4 inch. The average monthly loss was now deducted from the rainfall of each month, as previously determined, but in all cases where the remainder did not amount to the average minimum flow, the latter quantity was inserted.[1] The results will be found in Table No. 2, page 462.

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[1] The particulars of each month's supply can be consulted at the Institution.

TABLE No. 2.

Year.	Rain.			Loss.	Supply.
	Winter.	Summer.	Total.		
1851	15·76	19·98	35·74	13·94	21·80
1852	29·70	18·01	47·71	12·34	35·37
1853	20·13	19·03	39·16	12·01	27·15
1854	16·58	17·98	34·56	14·23	20·33
1855	10·91	17·89	28·80	14·23	14·57
1856	15·96	18·99	34·95	15·01	19·94
1857	22·03	12·51	34·54	11·79	22·75
1858	20·42	20·64	41·06	15·16	25·90
1859	21·68	13·33	35·01	11·86	23·15
1860	21·86	22·48	44·34	14·40	29·94
1861	17·58	21·87	39·45	13·68	25·77
1862	24·15	21·29	45·44	14·15	31·29
1863	19·12	23·72	42·84	14·38	28·46
1864	17·47	16·78	34·25	14·81	19·44
Average	19·53	18·89	38·42	13·71	24·71

Hence it appears that the loss varies in this district from 11·79 inches to 15·16 inches, the mean annual loss being 13·71 inches. The supply ranges from 14·57 inches to 35·37 inches, the mean annual supply being 24·71 inches. The years of maximum and minimum supply were also the years of maximum and minimum winter rain. It will likewise be perceived, that in the years 1856 and 1857, in which the rainfall only differed by 0·41 inch, the difference in the loss was 3·22 inches, arising from there having been a winter rainfall of 15·96 inches in the former, and of 22·03 inches in the latter year.

These conclusions, however, depend upon the correctness of two assumptions, viz., that there is a constant ratio between the rain fall near Carrickfergus and at Belfast; and that the observed monthly losses in the year 1864-5 enable the losses of the previous fourteen years to be estimated with sufficient accuracy. The method adopted does not present any results contrary to previous experience, or to such reasoning as can be applied to those results.

When the quantity and distribution of the available rain have been ascertained, the storage capacity required for the maintenance of a constant supply, amounting either to the whole, or to any part of the mean available rain, is merely a matter of arithmetical computation, and is measured by the longest period of defect of supply over demand. The particulars of the storage required for all quantities, from the mean annual supply down to that of the minimum year, have been calculated, and are given in terms of inches, days, and cubic feet per acre, in

TABLE No. 3.

Rain:— Inches.	Period on which Storage depends.	Storage.			Waste per Cent.	
		Inches.	Days.	Cubic Feet per Acre.		
24·71	78 months, May, 1853, to Nov., 1859 . .	29·22	431	106,000	0	Mean
24·00	78 months, ditto .	24·54	373	89,000	3	..
23·00	42 months, May, 1853, to Nov., 1856 . .	18·04	286	66,000	7	..
22·00	42 months, ditto .	15·39	255	56,000	11	..
21·00	35 months, Dec., 1853, to Nov., 1856 . .	11·17	194	41,000	15	..
20·00	33 months, Feb., 1854, to Nov., 1856 . .	9·57	175	35,000	19	..
19·00	6 months, May, 1857, to Nov. 1857 . .	6·98	134	25,000	23	..
18·28	6 months, ditto .	6·62	132	24,000	26	Average three dry years.
17·00	6 months, ditto .	5·98	129	22,000	31	..
16·00	6 months, ditto .	5·48	125	20,000	35	..
15·00	6 months, ditto .	4·98	121	18,000	39	..
14·57	6 months, ditto .	4·76	119	17,000	41	Minimum year.

To store the whole quantity yielded by the Woodburn district—24·71 inches—a reservoir capable of containing 106,000 cubic feet per acre, or 431 days' supply, would be necessary. To store 18·28 inches, the average of the three dry years, the reservoir must contain 24,000 cubic feet per acre, or a supply of 132 days. While for the minimum rain, 14·57 inches, a capacity of 17,000 cubic feet per acre, or a storage of 119 days, would be sufficient. For all quantities, from the minimum up to a little above the average of the three dry years, the storage depends on the period of six months' drought; for all quantities above this, it will depend upon periods varying from two years and nine months, to six years and a half. It should be remarked, that in calculating this table, the reservoir was supposed in each case to run down to emptiness, thus giving strictly the amount of storage required. Of course, in practice a margin of safety should be added. In Plate 25, diagrams 1 to 4 show the storage worked out for each month of the fourteen years, and for quantities of 24·72 inches, 22 inches, 20 inches, and 18 inches. Diagram 5 shows the state of the reservoir for a supply of 24 inches for eleven years and of 20 inches for the three dry years. In the last example, 11·44 inches, or 174 days of a constant supply of 24 inches are required; and the case is applicable, where special demands may be restricted, whenever there is any apprehension of failure. It is worthy of remark, that although with different assumed quantities of rain the water in store attains its minimum in different years, that minimum invariably occurs in the month of October.

From a consideration of the facts, it would appear, that, so far as regards the economical supply from the Woodburn district, it would not be prudent to attempt to store a greater quantity than about ten per cent. over the average of the three dry years, provided the extent of the gathering grounds could be increased. The maximum storage may, however, be provided in cases where natural reservoirs can be greatly increased in range at an inconsiderable expense; as at Lough Mourne, situated to the east of the Woodburn district, where a deep cut into the lake, and a short embankment of moderate height, would store the whole rain. It may be also observed, that when the supply of a town is derived from several separate streams, each having reservoirs, but all discharging eventually into the same conduit, the whole may be worked as one system, and the deficiency of storage on one stream may be supplemented by surplus storage on another, which presents more suitable sites for the construction of reservoirs.

The subject has hitherto been discussed only in relation to the economical supply of towns, but the consideration of the relative interests of the water companies and of the millowners must not be lost sight of. At first it may not be easy to perceive how injustice can arise by the purchase of water power, if, as is often the case, both the companies and the owners gain, the former by paying and the latter by receiving double its value. Yet the Engineer should never forget that his especial province is, to improve with as little incidental injury as possible. It is, therefore, clear, that he should always economize useless or injurious floods, if by pursuing that course, he can obtain his object at the same cost as by the destruction of mill-power.

The question of water power is, however, of too great importance to allow of its being treated in a satisfactory manner in the present Paper. It is one which is daily claiming more attention, and it suggests the inquiry whether the principle of economy in expenditure for providing a town supply should so far prevail, as to induce an injurious interference with the natural regimen of rivers, and the destruction by instalments of the whole water power of the country. Indications were not wanting, in the last session of Parliament, which would lead to the belief, that the Legislature would eventually greatly restrict, if not entirely prevent, such injudicious interference with rivers.

The proportion of the mean annual flow of the Woodburn river, applicable to the supply of the Woodlawn Mills, was determined from the daily gaugings already described. Those mills are the lowest on the stream except one, and receive the entire waters of both its branches, which flow from a rain basin of 4,750 acres. The water wheel is capable of consuming, at full work, 1,400 cubic feet per minute, or 840,000 cubic feet in the working day of ten hours. Whenever, therefore, the river delivered this, or any less quantity in twenty-four hours, the whole discharge, 583 cubic feet per minute, would be consumed by the mills, provided only that the mill ponds, at and above Woodlawn, were capable of containing twelve hours' supply, so that no waste should occur during the night. Those ponds have in reality twice that capacity.

The quantity at the gauges, corresponding to a discharge of 583 cubic feet per minute at the mills, was ascertained to be 418 cubic feet per minute. All gaugings exceeding that quantity were reduced to it, and all those which were less, or equal to it, were set down at the observed amount. In this way the daily quantity of water available for the supply of the wheel was accurately ascertained, and was compared with the whole flow of the stream, as determined by observation. The following are the results:—

TABLE NO. 4.

MONTHS.	Total Discharge.	Loss on Sundays and by Floods.	Available for Mills.	Per Cent.	Day's Full Work.
	Inches.	Inches.	Inches.		
July	0·36	. .	0·36	100	7·35
August . . .	0·53	0·12	0·41	78	8·44
September . .	2·55	1·48	1·07	42	21·91
October . . .	2·41	1·64	0·77	32	15·78
November . .	3·46	2·31	1·15	33	23·49
December . . .	2·71	1·48	1·23	45	25·13
January . . .	3·22	2·14	1·08	34	22·09
February . . .	2·31	1·38	0·93	40	19·00
March	2·19	1·15	1·04	48	21·32
April	0·47	. .	0·47	100	9·50
May	1·10	0·50	0·60	54	12·22
June	0·40	0·02	0·38	95	7·78
	21·71	12·22	9·49	43·69	194·01

Of the total flow off the ground, 21·71 inches, there was lost on Sundays and by floods 12·22 inches, leaving 9·49 inches available for the supply of the wheel.

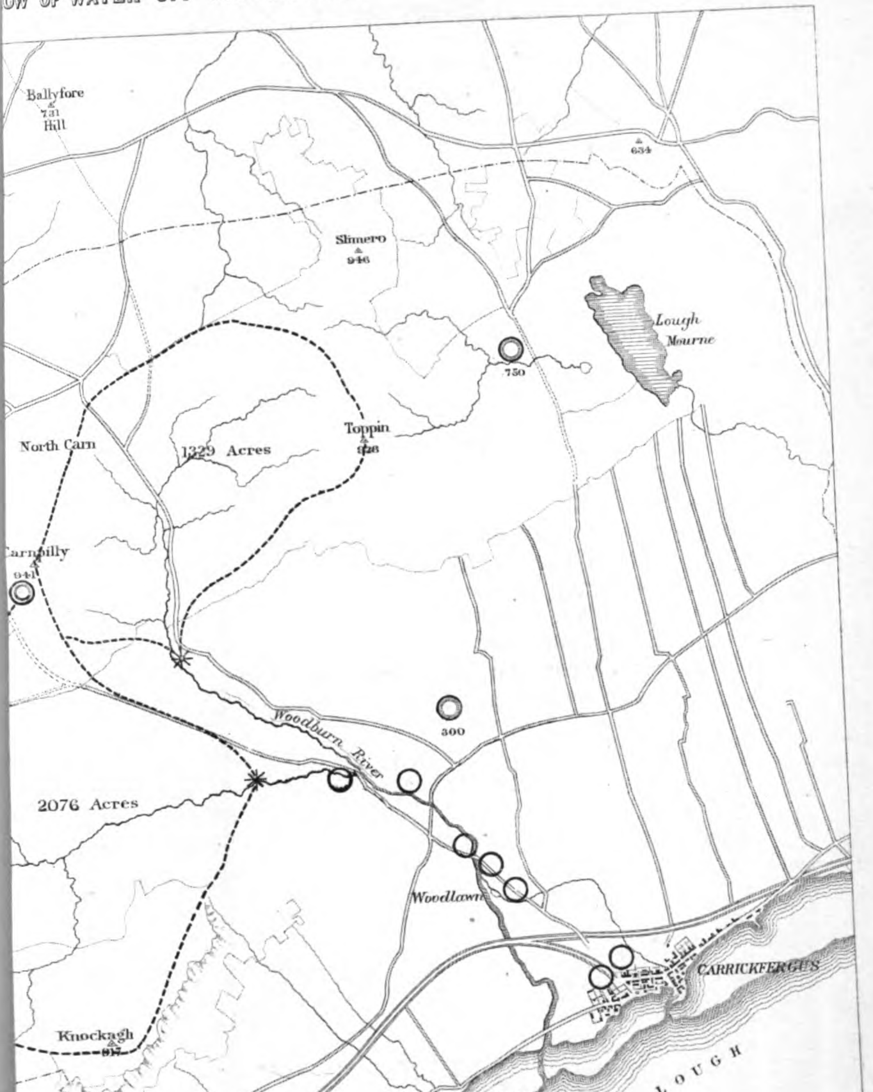
It must not, on this account, be concluded that 44 per cent. of the mean annual rain, is the proportion due as water compensation, nor indeed that the latter is a fixed quantity; for although it has been stated that one-third of the available rain will, in general, be an ample allowance, the quantity available for water power is dependent on so many circumstances, that each case requires its own solution. In this instance, the available quantity depends, among other things, upon the size of the wheel itself, which is capable of consuming 1·78 times the mean flow of the stream, and economizes 43·69 per cent. of the entire water, or in other words, 194 days' full work during the year. If the capacity of the wheel were reduced to 1·5 of the flow, the wheel would work for 213 days, and the yield would be 41·17 per cent. If again reduced to 1·25 of the flow, it would work 218 days, and give 39·14 per cent.; and if it were just equal to the flow, it would work 243 days, but would only yield 30·79 per cent., of the total available rain.

These facts may be taken as quite accurate in relation to the Woodlawn Mills; but it is not desired to extend them to other cases, nor to touch the question of the absolute quantity, much less the value, of the water to which the miller is entitled. And indeed, although the habit of rough generalization, and what is called "rapid approximation," may, of late years, have been forced on the profession, and may perhaps be excused by the exigencies of Parliamentary practice, it may be doubted, whether such treatment is suited to many of the questions which arise with regard to water supply, or to that critical consideration which all subjects are certain to receive at the Meetings of this Institution. Therefore, agreeable as might be the task of generalizing facts, which have been collected and arranged at an amount of cost and labour seemingly disproportioned to their worth, the Author has refrained from undertaking it, and has given them merely as some contribution, though a small one, towards a record of exact observation.

The communication is accompanied by a series of diagrams, from which Plates 24 and 25 have been compiled, and by a daily register of the rainfall in the Woodburn district, and at Queen's College, Belfast, from June 30th, 1864, to June 30th, 1865.

PLATE 24. VOL. XXV.

OW OF WATER OFF THE GROUND.


Ballyfore
731
Hill
634
Slimero
946
Lough
Mourne
750
Toppin
926
North Carn
1329 Acres
Carnbilly
941
Woodburn River
300
2076 Acres
Woodlawn
CARRICKFERGUS
Knockagh
917
BELFAST LOUGH
Scale of Miles.
0
¼
½
¾
1
2 Miles

KELL BROS. LITH. 8, CASTLE ST. HOLBORN.

edings, Institution of Civil Engineers, Vol. XXV Session 1865_66.

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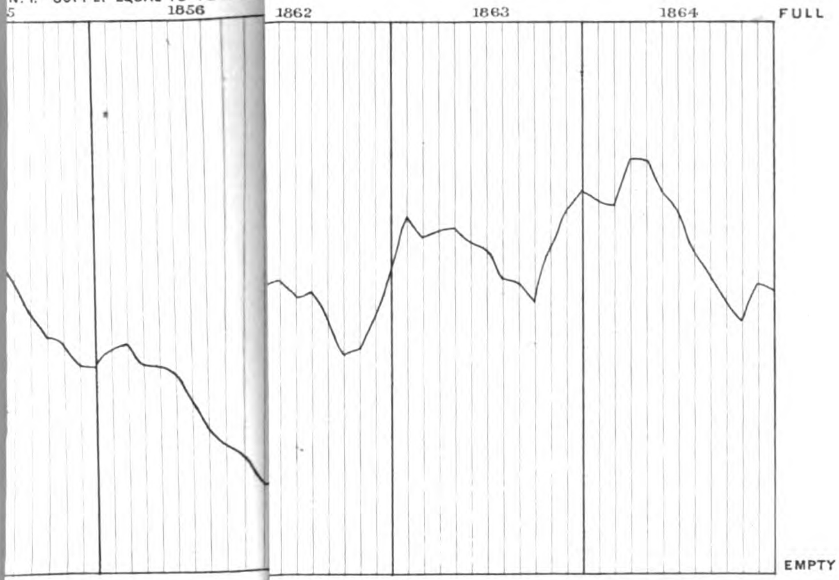

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APPENDIX.

Discharge of the **Woodburn Rivers** for Nine Months, from July 11, 1865, to March 31, 1866.

Month.	Woodburn. Observed Flow per Minute.		Total Observed Flow per Minute.	Run off Ground.	Calculated Rain 17·6 per cent. above Queen's College.	Queen's College Rain.	Estimated Flow.
	South.	North.					
1865.				Inches.	Inches.	Inches.	Inches.
July . .	56	31	87	0·23	1·23	1·047	0·40
August . .	263	188	451	1·63	3·88	3·303	1·08
September .	52	29	81	0·29	0·45	0·382	0·40
October . .	673	357	1,030	3·72	5·77	4·909	2·97
November .	958	571	1,529	5·34	4·40	3·736	4·20
December .	325	201	526	1·90	3·25	2·760	3·05
1866.							
January. .	769	488	1,257	4·54	4·15	3·523	3·95
February .	579	404	983	3·20	3·38	2·867	2·98
March . .	406	347	753	2·72	4·03	3·429	3·63
				23·57	30·54	25·956	22·66

Rain.

	Queen's College.	Woodburn.
From December 11 to December 31	1·272	1·30
January 31	3·523	4·70
February 28	2·867	3·30
March 31	3·429	3·55
	11·091	12·85

11·091 × 1·160. . . . . 12·87

11·091 × 1·176 . . . . 13·04

Remarks on Formulæ for Discharge over Notches or Weirs.

All formulæ for the discharge of water depend upon the principle that the velocity is proportional to the square root of the head. This theorem was published by Torricelli in the year 1643: it is a consequence of the laws of the fall of heavy bodies, and has been verified by numerous and independent experiments. It is true, that in a solitary instance, a few years ago, doubt was cast on this principle, but without success, and Mr. Francis, the accomplished author of the Lowell experiments, has shown how any one may verify it for himself with little trouble. It may therefore be taken to be a settled principle accepted by all hydraulicians.

The mean theoretical velocity of water passing over a notch, or weir, is—

$$V = \tfrac{2}{3}\sqrt{2\,g\,H}.^{*}$$

The actual velocity will be less than this, and the quantity discharged will be diminished by the effects of loss of velocity, and by contraction in the passage of the water over a notch or through an orifice. As those effects will fall upon the discharge, a single co-efficient has been sought for by experiment, which is called 'the co-efficient of discharge,' by giving a mean value to which the formula for weirs has been put into the simple shape—

$$Q = 214\,L\sqrt{H^{3}}.$$

It is evident that this co-efficient (214) cannot be constant, except Q be exactly proportional to H and L. All experiments prove that this is the case with regard to H, but not to L, and therefore M. D'Aubuisson and others have given co-efficients for different values of the latter quantity. For example, when the width of the weir is only one half that of the river channel, the co-efficient will be, not 214, but—

$$\left(214 \times \frac{{\cdot}617}{{\cdot}662}\right) = 199{\cdot}5$$

By carefully correcting the formula by the use of the proper co-efficients, results sufficiently accurate for all practical purposes will be obtained. Still the formula is not quite correct in principle, for contraction at the ends will take place in proportion to the height over the weir, and not to its length, and therefore the formula given by Mr. Francis will be more consistent with theory. The correctness of the co-efficients, 200 and 0·1, depends, however, upon the care taken in determining them experimentally, and must be accepted, unless those co-efficients are modified by future experiments, more extended, and acknowledged to be more exact. An example will afford the means of comparing the results given by each of the two formulæ.

A weir five feet long, and one half the breadth of the river, with 6 inches of water over it, will give—

By the ordinary formula without correction :—

Cubic Feet per Minute.

$$Q = 214\;L\sqrt{H^{3}} = 214 \times 5\sqrt{0{\cdot}5^{3}} \quad \ldots \quad = 378{\cdot}30$$

By the same, corrected for width of channel :—

$$Q = 214\frac{{\cdot}617}{{\cdot}662} \times 5\sqrt{\overline{0{\cdot}5}^{3}}\;. \quad \ldots\ldots\ldots \quad = 352{\cdot}59$$

By the Lowell formula :—

$$Q = 200\left(5 - (0{\cdot}2 \times 0{\cdot}5)\right)\overline{0{\cdot}5}^{\frac{3}{2}} \quad \ldots\ldots \quad = 352{\cdot}82$$

A weir 10 feet long, the full width of the river, with
12 inches over it, would give, by the ordinary formula 2140·00
By the Lowell formula . . . . 2000·00

The velocity of approach is generally very small, and it may be observed, that the Woodburn experiments were made, not for determining a co-efficient, but for the practical purpose of gauging the flow off the ground. To increase the confidence to be placed in their correctness, the Author has made accurate measurements of the river channel behind the notch on the South Woodburn, and by this means a close approximation to the velocity has been obtained. Taking it into account, he has increased the quantities given, in the ratio

$$\left(\frac{H+h}{H}\right)^{\frac{3}{2}}$$

h, being the height due to the velocity of approach, which will be sufficiently accurate for the purpose. The following are the results :—

Number of Observations.	Total Quantity Gauged.	Greatest Increase caused by Velocity of Approach in any one Observation.	Quantities corrected for Velocity of Approach.
	Inches.	Per Cent.	Inches.
237	4·50	0·12	4·51
88	5·87	0·42	5·89
22	3·03	0·56	3·05
5	1·11	1·20	1·12
7	2·59	3·02	2·67
5	3·33	5·19	3·50
1	1·28	8·78	1·39
365	21·71	..	22·13

Hence the total error could not possibly amount to 0·42 inch, or two per cent. of the whole quantity gauged, which is quite inappreciable in a case where it is shown that from natural causes the evaporation, or loss, and, consequently, the flow, may vary 13 per cent.

The number of experiments, though considerable, 1,258, could not produce, even if ten times extended, results absolutely accurate, except the rate of increase or decrease between each observation were constant. This was certainly not the case in the Woodburn district; and, in fact, to secure such accuracy, nothing less than an infinite number of experiments could be sufficient. Absolutely correct gauging would therefore appear to be a practical impossibility, yet such a method, as indicated, was actually carried out in Ireland in the year 1851, by Mr. Thomas J. Mulvany, M. Inst. C.E., Ireland.[1]

A less exact method would be to place a float fitted with a pencil, which would register the highest and the lowest state of the water between each observation, and thus three daily observations might be had, at one visit. But a very close approximation to the gross annual discharge may be made by one daily observation only, for the errors of excess and defect, inseparable from this latter method, will affect the results less and less as the experiments increase in number, and, if very numerous, will nearly equate each other. In this case the heights over the notch on each branch of the stream were noted by one person, and therefore not simultaneously. A comparison of the separate results will show this tendency to the equation of errors, and therefore the observations are, in fact, practically accurate. One circumstance favourable to those experiments has been omitted to be mentioned, namely, both notches were placed above all the mills, and also above any artificial obstruction to the flow of the streams.

The combined discharge of both the Woodburn rivers for the year were reduced after the method proposed by Mr. James Leslie, M. Inst. C.E.[2]

	Cubic Feet per Minute.
The average of the lower fourth was	74
„ middle half .	252
„ highest fourth .	1,485
Final average, excluding floods .	184

Which is equal to 7·83 inches off the ground.

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[1] *Vide* Transactions Inst. C.E. of Ireland, vol. iv., part ii., p. 18.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. x., p. 327.

[Mr. MANNING

Mr. MANNING stated, that on being employed on the occasion referred to at the commencement of the Paper, he endeavoured to ascertain all that had been published on the subject of the rainfall of the district; and he found that the estimates varied from 33 inches to 18 inches per annum, and the compensation to be given to millowners was variously computed at from 5 inches to $9\frac{1}{4}$ inches flowing from the ground. As such uncertainty would lead to a conflict of professional opinion in Parliament, he considered the most proper course would be to appeal to facts, and accordingly he commenced the series of observations which he had just laid before the Institution. He felt the responsibility he had undertaken, because he was quite aware, he must not only be sensible, that he had presented statements which he believed to be true, but that he had neither stated anything carelessly, nor omitted the use of any means of insuring accuracy. He also felt that he ought not to conceal the slightest circumstance, whether it influenced the final results or not. He would, therefore, enter upon one or two matters which might need explanation.

In the first place he had given the record of the rainfall at Queen's College, Belfast, as being for 14 years; to be strictly accurate, it was the record for 13 years and 9 months, and for the other three months he had been obliged to get the record of another gauge. He had likewise given the observations of three rain gauges in the Woodburn district at elevations of 900 feet, 750 feet, and 300 feet, above the level of the sea, but to the gauge at an elevation of 750 feet an accident occurred on two occasions, so that he was not able to produce the precise results of that gauge, but the error could not amount to more than $\frac{1}{10}$th of an inch.

He had stated that all the observations of the flow off the ground had been calculated by the Lowell formula. That was substantially correct, but to insure accuracy, it was necessary to contract the dimensions of the notch. The notch was about one-fifth the width of the stream, with a waste board at each side to pass large floods. For if it were wide enough to give the quantities of large floods, it would not give with certainty the ordinary flow of the stream. Out of 730 observations of the flow of water, about thirty, being those of large floods, were not got by the Lowell formula, but by approximate methods; but as the whole quantity thus measured amounted only to 3·8 inches, even a very considerable error in their application could not affect the result in any appreciable way, and by using them no water whatsoever was allowed to pass unmeasured.

The matters treated of in the Paper might be classed as observed facts; the assumptions made in the absence of more extended observations; and the results deducible from those observations and assumptions. The observed facts were entitled to be considered correct with this qualification, that in respect of the number of cubic feet of water flowing down the river only one observation had been made per day throughout the year. The assumptions were two in number. The first was, that from the observations of the flow for one year could be calculated with sufficient accuracy the flow off the ground for a number of years—that was a matter which could only be disproved or substantiated by further experiment, the recorded experiments were for one year. Mr. Lanyon, the Engineer for the Belfast Water Works, finding the notches erected, and in working order, had continued the experiments for nine months longer, but unfortunately he had not taken the rain-gauge observations. Those of the flow, however, gave an opportunity of testing the accuracy of the methods adopted in the Paper in a very severe manner. The rainfall recorded at Queen's College, Belfast, from July 11th, 1865, to March 31st, 1866, was 25·96 inches. If that were increased in the proportion 1,176 to 1,000, the rainfall to be expected at Woodburn would be 30·54 inches, and calculating by the rules in the Paper, the flow off the ground would be 22·66 inches; the actual flow was 23·57 inches, differing from the theoretical flow by less than 1 inch, which was some confirmation of the soundness of the calculations. The other assumption was as to the ratio of the fall of rain; that between Belfast and Woodburn was taken as constant, not every day, or every month, but over a number of years. Then resuming on the 11th of December the rain-gauge observations which Mr. Lanyon had discontinued, the register at Queen's College from December 11th to March 31st was found to give 11·09 inches; following the ratio 1,176 to 1,000, this would give 13·04 inches, but adding only 16 per cent., as adopted in the Paper, the estimated rain at Woodburn would be 12·87 inches; the quantity actually observed was 12·85 inches.

He would now shortly state the general results. The rainfall at Woodburn, at an average elevation of 600 feet above Queen's College, Belfast, was from 16 to 18 per cent. greater. The rain at Woodburn at elevations of 900 feet, 750 feet, and 350 feet was nearly the same; the average of the three dry years was nearly $\frac{6}{7}$ths of the mean annual rain. The minimum rain was $\frac{3}{4}$ths of the mean annual rain. The evaporation or loss for the year 1864-5 was 14 inches; and this quantity might be expected to vary in different years, from $11\frac{3}{4}$ inches to $15\frac{1}{4}$ inches. The average flow off the ground was $24\frac{3}{4}$ inches. The average of the gross winter's rain was about 5 per cent. over the average flow off the ground in the three dry years. The storage depended, not only upon the absolute quantity proposed to be stored, but on its proportion to the total rain, and varied from 120 days to 430 days. For example, 20 inches required 175 days' storage, and 22 inches required 255 days, so that when it was said that a certain storage was required, it was necessary to know what proportion of the total rain was proposed to be stored.

As regarded the mills, it had been shown that at Woodlawn in 1865, 44 per cent. of the entire flow of the stream was consumed. The wheel was constructed to consume at full work 1·78 times the mean flow of the stream, that was, the mean annual flow of the stream was just 800 cubic feet in a minute, and the full quantity the wheel could consume with buckets two-thirds filled was 1,400 feet. If the wheels were reduced in size, there would be a less per centage, in the proportion stated in the Paper.

Mr. J. F. Bateman was afraid he must, to some extent, differ from the conclusions arrived at; not as to the facts, but as to the mode of using them. If he understood aright, the notch was made of the same width as the stream, and then the Lowell formula was applied. He thought that formula was as nearly as possible equivalent to the ordinary coefficient of 5·1 for the velocity of water discharged under pressure; the mean velocity over a notch or weir being two-thirds of that amount. He knew from experience that if the notch was as wide, or nearly as wide as the stream on which it was placed, the flood water could not be measured in that way, and could not be included in the total quantity which flowed from the ground; it would be considerably larger than any calculation deduced from the depth flowing over the notch. The water, at such times, was so great in volume, and approached the notch with a velocity so much greater than that apparently due to the measured depth, that no correct deductions could be arrived at, by the application of any ordinary formula. Then again, observations taken only once in the day, might exclude, in many cases, a large amount of flood water. The floods of the Woodburn district at this maximum amounted to 400 times or 500 times the ordinary flow in dry weather, and though the flood frequently remained only for an hour or two, or not so long; yet during the time it continued, it carried a large volume of water, which, if not included in the single observation of the day, was necessarily omitted from the calculation; therefore he thought it probable, that the quantities of water which resulted from the measurements recorded in the Paper were below the real amounts. He was aware there might be an error the other way, through two or three heavy floods having been accidentally included, when the measurements were taken. He had, however, no doubt, that the observations were as correct as any of the same kind could be, unless made day by day from a reservoir, or large surface of water, where the objection to the use of the ordinary formula would not exist. The Author was perfectly right in the course he pursued, if he wanted to ascertain the probable state of things in districts where there were no records of the annual difference in the fall of rain between one place and another, or in the case of one place, where the observations extended only over two or three years, and another where the series were continued for a long period of years. In such cases the only way in which a conclusion could be arrived at, was by assuming the difference observed upon one year, or two, or three years as a tolerably constant quantity; but that might in many years be erroneous. Therefore the deductions, though carefully worked out, must be taken as approximate only, and could not be depended upon as a general rule. With reference to the mills, the instance given was that of a large water wheel, which, being of an unusual size in proportion to the stream, was able to consume a large portion of the descending water. But that portion must not be taken as the quantity which could be most usefully applied to the wheel, because it was the amount between exhaustion one day and repletion another. A regulated daily quantity of water, much less than that which was required to work the wheel at its full power, would have been more beneficial in the working of the mill than that alternate deficiency and excess. In all experiments of this character, however, it was important to note the geological structure of a country, and the Woodburn district was remarkable, the chalk being indurated into an extremely cavernous limestone, by the heat resulting from the eruption or protrusion of the overlying basaltic, or trap rock. The water which entered the crevices and various swallow holes was impounded and re-delivered in small quantities regularly and constantly throughout the year, so that a large supply was stored for mill purposes, and given out more uniformly than could have been the case had the district been a hard, unbroken surface, allowing the water to flow over and off the ground instead of into and through it. That accounted for the peculiarity of the mill power being large, though the wheel was large in proportion to the volume; but it was an additional reason why these circumstances should be kept in mind, when conclusions were drawn with regard to different parts of the country. Still, the observations were useful, as showing the proportion of the whole amount of the stream which a water wheel so constructed was capable of employing. Indeed, with the modifications he had pointed out, all the investigations of the Author were exceedingly valuable. He was happy to find, as being responsible for the Belfast Water Works, that the results shown in the Paper were so nearly the same as those which, in the absence of those careful gaugings, he had himself assumed from the best information the country afforded. When he first reported upon those works fifteen years ago, before he knew what the actual rainfall was, he estimated what would be the results of various quantities. And as his experience of the district was enlarged he brought down the quantity as varying from 18 inches to 24 inches.

Mr. BEARDMORE quite admitted the difficulty of gauging floods, for the water at such times might pass by without record. In some cases he had adopted a mode of gauging during flood, by turning the notch into a sluice, by lifting the notch-board, and registering the height of both the head and the tail water. When the water began to head, and to push through the notch, it was better to endeavour to take the notch away, either by drawing the board, or by closing it and drawing a side-gate; the upper and lower gauges would then give the sectional area of water passing, and to calculate the quantity of water by the fall was then a simple matter.

He had tried gauging into boxes, as against calculation over a notch or weir, when the water was wire-drawn in approaching the notch, and the formula was thrown out a good deal. But it was quite easy to ascertain the velocity of a stream approaching a weir in flood, by having two gauging-posts, and placing them, with the lip of the weir for zero, in such a position as to give the depth flowing actually at the weir, and the depth at any given distance from it up the centre of the stream. If required, a third gauge could be placed so as to obtain the curve that the water assumed when approaching the weir; that would give, by calculation, the velocity of the approaching current, and the additional gauging would be a check upon the observations, besides indicating at once when the water rose above its normal volume, and consequently when the overfall formula became liable to correction.

With regard to the frequency of gauging, no doubt it would be better if the flow were taken at least three times per day; but he believed the Author had selected the time when the stream was least affected by the working of the mills, or by other circumstances, so that the result was fair—the stream being, to some extent, equalized by the mill-dams above.

Next, as to the mill question. Those mills worked under the Factory Act, and consequently had ponds, by which the night-water was stored, so that the power would be adjusted to nearly double the usual flow of the stream; but, though it had been objected that the Woodlawn wheel was of rather a high power, that circumstance only enabled it to do fairly the amount of work which the stream would give with the assistance of the pond. It was an important fact that, while the stream might be called high-powered, yet as much as 56 per cent. ran to waste, so that the Woodburn district gave a satisfactory example of the large quantity of water available in certain cases. The geological formation of that district was remarkable in one respect; the hills were capped with a vast bed of columnar basalt, under which reposed the hard crystalline chalk. The water falling in the back country was absorbed into the strata beneath the basaltic rocks, and, passing through the cavernous chalk, came out in the form of springs on the face of the slopes rising from Belfast Lough.

There was one valley of considerable area, terminating in a swallow called Lignaca, where the water disappeared, at the northern side of the hills, to reappear on the southern face, at two or three miles' distance, there forming copious springs, which, if not now, he hoped would be hereafter taken for the supply of Belfast or some future city. That was the largest instance of a subterranean flow he had ever seen in these islands. It was a large, perpetual stream, and not like the swallows in Hertfordshire, where, for the greater part of the year, there was no stream.

Whether the calculations deduced from observations of twelve months' duration, established an absolute proportion between the gauges and the long series of rainfall observations at Belfast, was open to doubt: but it was remarkable that the Woodburn hills gave a very uniform amount of rain, and a short series was thus fairly comparable. The rain beat against the steep face of the hills, which were not high enough to prevent the clouds passing over; there was not, therefore, that inequality of fall which occurred with higher ranges. And there was an internal proof of accuracy in the record of the fall at the several elevations mentioned having been tested with that at Belfast; the Belfast gauges being known to have been kept with accuracy for many years. The proportion of flow between the several months was very consistent with the observations he had himself made in other districts of the same geological character, but where the rainfall was much less in the course of the year. During the three winter months of November, December, and January—and sometimes February—there flowed from the ground nearly as much rain as fell; therefore it was not surprising that for two of the months, when there was generally even more water than a rain-gauge would show, the Author should have given varying amounts. Those months were influenced by falls of snow, which were difficult to ascertain correctly. The Paper established how much water could be obtained, and how much there still was to spare where mills were extremely high-powered, a state of things that prevailed very much in the south of England, where, although there was nothing like the same amount of rain, there was a large surplus of flood water.

Mr. S. C. Homersham agreed as to the necessity of having extremely large reservoirs, if the whole flood water that flowed off a district was to be impounded. Practically, it was impossible to make the whole of the water that fell upon steep hills, of an impermeable character, available. He was also of opinion that, where an account of the actual rainfall in a given district, for a lengthened period, could be obtained, the results were more accurate than when based upon assumptions. If the rainfall of one district was ascertained for one year only, and then compared with that of another district where observations had been made for a series of years, the results might not be accurate, or even approximately accurate. That fact was well ascertained from numerous returns, made on an extensive scale and long continued. He understood from the Paper, that the Woodburn observations upon rainfall were made with a gauge having a float and graduated staff, and he begged to inquire whether the staff rose above the surface of the gauge.

Mr. **Manning** said, the staff was only used for a moment at each observation, and was then removed. The size of the hole through which the rain passed was about half an inch. The size of the float, in comparison with the area of the rain gauge, was small.

Mr. **Homersham** believed that the indications of such a gauge would be accurate. He had been desirous of knowing whether the staff rose above the surface of the gauge, because observations made with rain-gauges so constructed were not to be relied on. With the gauge actually employed, only a small surface of the water contained in the gauge was covered with the float, and there was also a small hole above the water in the centre of the gauge. It had been erroneously stated[1] that, if the water was thus exposed, a large portion would be lost by evaporation. He had made experiments very carefully, in order to ascertain whether that would be the consequence of using a rain-gauge so constructed, and he had found that no such loss took place; and, he might add, that rain-gauges similar to those used by him since 1847, were now generally employed by meteorologists.

Mr. **Robert Rawlinson, C. B.**, thought the experiments, however careful and laborious, were on too limited a scale, and extended over too short a period to enable any practically useful application to be made of them to general principles, and would, therefore, reserve his observations for an occasion upon which the whole question of rainfall and water supply might be adequately discussed.

Mr. **C. Greaves** remarked, that the district in which the observations were made, was one which must be characterized as very moist, and that the amount of loss calculated by the Author was really to be treated as the amount of evaporation, mostly from the surface of the ground, leaving a large remainder available from the rainfall. In the Thames and other rivers in the home counties, not more than 25 per cent. of the whole rainfall could be registered, the evaporation amounting to 75 per cent. Rain-gauges were now multiplied all over the kingdom, and observations were made in every direction; but the process and result of evaporation had not been sufficiently studied. It was quite as important a subject as rainfall.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. vii., pp. 287-8.

Mr. M. Scott was much struck with the circumstance that all the Woodburn gauges, set at varying elevations, of 900 feet, 750 feet, and 300 feet respectively, seemed to give nearly the same amount of rainfall, which was not consistent with his own experience in other districts. His observations went to prove, that as the elevation increased, so did the quantity of rain, up to a height of 2,000 feet; and that a gauge placed close to the surface of the earth collected more water than one placed several feet above the surface.

Mr. C. E. Cawley considered that no reliance could be placed upon the storing up of extra floods for the supply of a town. With regard to the utilization by mills, although he had no doubt it was quite true, that a constant was more valuable than an intermittent supply, yet it should be considered that where a wheel consumed a considerable quantity beyond the minimum, or beyond the average flow, the mill must be provided with other power, to be applied when the supply of water was not sufficient. That must be done either by means of steam power, or by storing water, to be used during the minimum flow. But though, theoretically, power thus obtained was not so valuable as that produced by a regular current, it by no means followed that such a wheel was compensated by giving a constant supply of one half, or one third its capacity, although that might equal the average it had used. He considered, however, that a greater number of facts must be collected before the question could be fully discussed.

Mr. Manning in reply, said he agreed with almost all the remarks that had been elicited during the discussion. He thought, at the same time, there were one or two points which he could not permit to pass without notice; for if admitted, their tendency would be to invalidate conclusions which had been arrived at with great care and labour. It had been stated that his observations were, after all, only approximate, as the "velocity of approach" had not been considered, and there had been only one observation each day, but that, nevertheless, the results accorded closely with those which had been arrived at without experiments. In reference to the subject, he found the following statements in a printed report upon the supply of water to the town of Belfast.[1] At page 11 it was stated that 24 inches of rain could be collected; at page 14, 30 inches; at page 18 there was a table showing the supply to be derived from available rainfalls of 36 inches, 30 inches, and 24 inches: however, at page 19, it was observed that, as the mills were to be first supplied, it would not be prudent to depend on more than 24 inches; but again, at page 21, the quantity which might be relied on, even after a succession of dry seasons, was stated to be from 27 to 28 inches. In 1855, the former calculations as to the probable quantity which could be obtained for the Woodburn rivers was somewhat modified; but at page 25 the future supply was estimated as likely to exceed 27 inches. In a Report published in 1864, in which the merits of two rival bills were discussed, the estimated supply was 18 inches. With regard to the compensation water, at page 19 it was stated to be 9¼ inches, which was nearly identical with the result obtained for 1864-5, by himself. At page 25, the quantity given was only 5 inches, and in the report of 1864 it was about 6 inches. As to the storage, it was stated at page 15, that for an available rainfall of about 30 inches, the space requisite for impounding all the water of wet seasons, so as to insure a regular average quantity at all periods, should be from 30,000 to 40,000 cubic feet per acre—from 100 to 135 days' supply; at page 20 this was increased to 150 days. If by the words, "all the water of wet seasons," &c., it was meant that the total average flow was to be stored, 431 days, and not 150 days, would be required. As to mill power, it was quite true that the supply, if variable, was not so valuable as if it were constant; but when it was suggested that the dimensions of the wheel should be changed for each variation in the supply, it appeared to have been forgotten that auxiliary steam power might be applied, and the water wheel worked at full power for as many hours each day as the supply would allow; that was the arrangement at Woodlawn, and at nearly every other mill in the district.

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[1] *Vide* "Report on the Supply of Water to the Town of Belfast." By John Frederick Bateman, C.E., F.G.S. Manchester, 1856.

With reference to the formula, he agreed, that by supposing a notch, of only 2½ inches width, with 12½ inches, or any greater height of water running over it, the results given would be absurd, and that therefore, in strictness, it could not be taken as a general formula; but that was just what Mr. Francis, the author of the formula, said it was not. He gave, on the contrary, several conditions under which it must be used; one being that the length should be equal to, or greater than three times the height. But even taking the formula as general, it did not follow that because values for L and H might be substituted, which would make the term of the equation between the brackets vanish, or become negative, that the formula would indicate, as had been stated, a total cessation of the flow, or a reverse flow. He would add that the formula

$$Q = 214\ L\ \sqrt{H^3}$$

had been represented as giving the quantities due to the full force of gravity, without any allowance for loss of velocity or contraction, but that remark was equivalent to denying that the velocity of water issuing from an orifice was proportional to the square root of the height, a principle which had been accepted as correct by all hydraulicians for more than 200 years, and the truth of which might be demonstrated in various ways.

He had not intended, however, to investigate formulæ for the discharge of water, but merely to use a well-established rule for calculating the flow off the ground; but as the subject had been left in an unsatisfactory state, he would offer some remarks on those formulæ in an Appendix. He would add that the width of the notch was about one-fifth that of the stream above it; he had not taken into consideration the velocity of floods, but he believed the quantity stated was very near the quantity discharged.

Mr. Fowler, President, thought the Author deserved the thanks of the Members for the careful and exact data he had presented to the Institution; and he hoped that a Paper would be prepared on this subject, which would afford scope for that ample discussion which appeared to be desired.

May 1, 1866.

JOHN FOWLER, President,
in the Chair.

The following candidates were balloted for and duly elected:—James Richardson Forman, William Husband, Thomas Meik, William Richard Morris, and James Muir, as Members; Henry Bessemer, William Brookes, Rowland Brotherhood, Joseph Green Cooke, John Cundy, Frederick George Finch, Charles Goolden, M.A., Henry George Clopper Ketchum, William Carey Leechman, Marcus Smith, and Matthias Erasmus Wesley, as Associates.

The discussion upon the Paper No. 1,153, "On the Flow of Water off the Ground, &c.," was continued throughout the evening, to the exclusion of any other subject.

May 8, 1866.

JOHN FOWLER, President,
in the Chair.

No. 1,133.—"On the Water Supply of the City of Paris."[1] By GEORGE ROWDEN BURNELL, M. Inst. C.E.

THE improvement of the water supply of Paris has, for some time, seriously occupied the attention of the Town Council of that city; and the methods actually adopted both for procuring the quantity required, and for distributing it amongst the inhabitants, have been the subject of much controversy. The Author, desirous of collecting the means of forming a judgment as to the course pursued, placed himself in communication with M. Belgrand, the Engineer-in-chief of the above service, and from that gentleman obtained the bulk of the information contained in this Paper, availing himself also of published documents.

It would be out of place to allude here to the various steps taken before the year 1860. The history of what had been done previously may be read in detail, in various well-known treatises.[2] It may suffice for the present to mention, that the Prefect of the Seine intrusted to M. Belgrand a careful review of the hydrographical basin comprised under the general name of the Basin of the Seine. He recognized that at that time, 1860, the city of Paris only received the following quantity of water, from the sources mentioned:—

	Cubic Feet.
The water of the canal de l'Ourc	3,671,200
Ditto of the Seine, from the pumps of Chaillot .	1,412,000
Ditto of the Seine, at Quai d'Austerlitz . . .	28,240
Ditto of the aqueduct of Arceuil	56,480
Ditto of the well of Grenelle	31,770
Ditto of the springs on the north side of Paris, and of the Près St. Gervais	17,650
	5,217,340,

Or, 32,503,028 gallons per day.

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[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

[2] *Vide* Genieys, "Essai sur les moyens de conduire, d'élever, et de distribuer les Eaux." Emery, "Statistique des égouts de la ville de Paris." "Annales des Ponts et Chaussées, for 1836," &c., &c. 8vo., Paris.

This quantity had to meet the wants of a population, then calculated to amount to more than 1,600,000. The total amount of distribution per head per day would have been more than 20 gallons, if the whole had been exclusively devoted to the use of the citizens; but it is necessary to make a considerable deduction for what was consumed for municipal services, especially as in those days the water was not laid on to the private houses in the same manner that it is now, so that the actual quantity was far less than would appear from the return. The quality also was objectionable. That of the supply from the canal de l'Ourc, on account of the impurities contracted during the flow, or during the time that the waters remained exposed in the Bassin de la Villette; and that from the Seine, because it was, for the most part, obtained from below Paris, and therefore was exposed to much contamination. This was very marked at the intake at Chaillot, situated just below the point of discharge of the large intercepting sewer of the left bank of the river. The waters supplied by the aqueduct of Arceuil, though tolerably limpid, were, like those furnished by the springs rising on the north side of Paris and in the Près St. Gervais, excessively and permanently hard. In fact, both in quantity and quality, the water supply of Paris was lamentably deficient.

M. Belgrand had long studied the Paris Basin with regard to its capacity for furnishing a water supply, and he had published at various periods[1] an exhaustive series of memoirs upon the conditions of the geology of the district, and upon its meteorology, as likely to affect that question. He found that the Basin of the Seine was formed of a part of the granite eruption of the Morven, succeeded by the Jurassic deposits, without the intervention of the old and the new red sandstones, or any trace of the carboniferous formations; the Jurassic deposits being, in their turn, succeeded by the chalk, and the whole being covered with the tertiary strata around Paris itself. The granite of the Morven is only 137½ miles, or 140 miles from Paris, and it yields abundant floods, which hitherto have been allowed to run to waste. But the idea of forming large storage reservoirs in this case was rejected, through mistrust of the quality of the waters so collected, and preference was given to the waters that filtered through the calcareous formations. It is to be remarked that the French Engineers and chemists attach great importance to the presence of certain proportions of the bi-carbonate of lime in the water distributed for drinking purposes; and they hold, that about the proportion of that salt sufficient to produce 16° of Dr. Clark's scale of hardness is not only unobjectionable, but is positively beneficial. This is precisely the composition of the chalk waters; and, therefore, that source was adopted.

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[1] *Vide* "Annales des Ponts et Chaussées." September and October 1846, and January, February, March, and April, 1852. 8vo. Paris. Attention is particularly directed to these documents, in contrast with the Reports of the Board of Health in England.

It is not intended to enter upon the question of the geology of the Paris Basin; but merely to show that neither time nor study has been spared to complete the scheme elaborated for the supply of Paris. The first project was to resort to the sources that feed the Somme Soude, an affluent of the Marne, and to conduct the waters to about the height of 260 feet above the level of the sea. The supply that the town could depend upon from the united sources, was calculated at about 3,557,905 cubic feet per day; which was nearly as much as the total quantity the present water supply of the town yielded; and this project seemed so reasonable, that the Conseil Municipale ordered the definitive studies to be proceeded with. The scheme was, however, subsequently, to a considerable extent, modified, and the Engineer recommended that instead of the springs of the Somme Soude, the springs of the Surmellin, the Sourdin, and the Dhuis, which all rise in the same chalk valley as the Somme Soude, should be led to Paris by one aqueduct. The city met with the usual amount of opposition from the proprietors of water privileges, and the intention of using the waters of the Sourdin has, therefore, been abandoned, for the present; and the waters of the Dhuis, and of the Surmellin are alone brought to Paris from the plains of Champagne. An ample compensation for the quantity thus lost has been suggested, in the sources of the Vanne, a small perennial stream that rises a little to the west of Troyes, and after flowing through Sens, falls into the Seine. This source of supply will be led to Paris by an aqueduct, along which it will flow by gravitation, and in addition the city has purchased the right to take a considerable quantity of water from the River Marne, at St. Maur, above its junction with the Seine, and at the mills of Trilbardou, on the course of the same river. The Town Council will thus command an additional supply of 20 million gallons per day, to be pumped into the canal de l'Ourc; and it has also the right of taking a further supply from Les Isles Méldouses, which would supplement the quantity derived from that canal. A considerable quantity of fresh water for drinking purposes is expected from several Artesian wells, two of which have been commenced in the high quarter of Paris; though the results of the boring of Passy are not such as to inspire much confidence in this source of supply. The changes that have thus been introduced in the scheme, are, as will be seen, very great. The waters of the Dhuis reach the city at a higher level than had been calculated; the waters of the Vanne arrive at a lower point, and in a different quarter than had been provided; the waters of the Somme Soude have been at present passed over, and are left for the future extension of the works.

Sufficient progress has been made in leading the waters of the Dhuis and the Surmellin, to allow of the supply of the high quarters of the town. The springs of the first have yielded in the driest season, for twenty-one years, about 6,698,400 gallons per day. The springs of the Surmellin yield about from 450,000 gallons, to 670,000 gallons per day; but the Engineers calculate that by a series of operations connected with the drainage of the head-lands surrounding these springs, the quantity to be obtained from both these sources will be at least equal to 9,000,000 gallons per day, even during periods of prolonged drought. The aqueduct of masonry, that conveys the above waters, is never less than 4 feet 6 inches high, and is at times increased to 5 feet. It is carried on arches in those positions where the depression of the valleys does not exceed 33 feet; and where greater, the aqueduct is replaced by a reversed syphon, of cast iron, 3 feet 4 inches, or 3 feet 8 inches internal diameter. The section of the aqueduct is in part ovoidal, but in other places the sides are made with a curvilinear batter, according to the nature of the strata traversed. It will deliver 9,810,476 gallons per day, when running to within 1 foot of the crown of the arch. It has a general inclination of $\frac{1}{10000}$, but that of the syphons is $\frac{55}{100000}$, in order to accelerate the discharge through them; and it is calculated that it will deliver the water at the reservoirs lately built at Menilmontant, at the height of 301 feet above the level of the Seine. The aqueduct passes for a long time upon the left bank of the Dhuis; it then follows the valley of the Marne to Chalifert, where it is carried over the river on a bridge of singular construction on account of its narrowness and the great span of its arches; and then it passes on the right bank of the Marne and Seine until it arrives at the reservoirs. The materials employed in the execution of the masonry are the pierre meulière set in the cement of Vassy; the whole of the interior and exterior of the arches being 'rendered,' to obviate any interference with the flow in consequence of the roughness of the surface, and to prevent the infiltration of the land waters.

The water from the Marne, at St. Maur, is distributed from the second story of the reservoirs at Menil-montant; which, in consequence of the formation of the ground, is built in two tiers of arches, commanding different parts of the city. There is a smaller reservoir, also in two tiers, near the site of the old telegraph at Belleville, which is intended for the service of the higher parts of Paris. This reservoir will be filled by a steam engine, and is, in all respects, similar to that erected at Montmartre, for the service of the houses upon that hill. The quantity pumped from the Marne is calculated to be about 9,000,000 gallons per day, when all the water wheels are in work ; and the height to which the water will be raised is calculated at about 287 feet 7 inches above the level of the Seine. It is intended, eventually, to pump the same quantity from the Marne at Les Isles Méldouses; but this will be reserved to add to the supply derived from the canal de l'Ourc, and will be exclusively set apart for the public fountains and the municipal wants, which, it is believed, will increase with the gradual extension of Paris. The waters of the Marne are tolerably pure and limpid, but are rather hard, and contain a considerable proportion of bi-carbonate of lime, in conjunction with a sensible quantity of carbonate of magnesia, contracted in their passage over the formations of gypsum and meulière, after the river has received the waters of the Dhuis and the Surmellin. The future destination of this water will be to supply the public fountains, and the municipal services; but the Author is inclined to suspect that at present there will be little effort to separate the two sources.

On the left bank of the Seine, the operations are very extensive. In the valley of the Vanne have been purchased a series of springs, which rise from the chalk formation at Armentières, on the road from Sens to Troyes; and their volume is increased by the springs of Chigy, St. Philibert, Malhortie, Theil, Noe, &c., which are all of the same nature. The total length of the aqueduct, by which these waters will be led to Paris, will be about 104 English miles. The course of this aqueduct is along the right bank of the Vanne, till near Sens; then along the bank of the Yonne, between Sens and Pont-sur-Vanne; it then follows the left bank of the Yonne, and passing the Loing, above Moiret, is continued through the forest of Fontainebleau, and leaves the town on the left, passes Melun and Corbeil on the right; after crossing by means of syphons the valleys of Enone and of St. Orge, and it at length arrives at the heights of Montrouge, after passing the Bièvre, a little above the point of junction of that river with the Seine. As regards the delivery, in the report addressed to the Conseil Municipale for 1858, the height was estimated at only 141 feet above the Seine, at the bridge of Tournelle; but the quantity was calculated to be equal to 22,328,000 gallons per day, sufficient for the supply of all the low-lying quarters on the left bank of the Seine, with good spring-water. The waters proposed to be brought to the capital by this means are of a superior description, and are considered by French chemists to be at least equal to those furnished by the Somme Soude. The supply is exclusively derived from the chalk formation. The aqueduct is intended to be constructed in the manner, and with the materials described for that of the Dhuis.

The city is energetically turning to account the sources abovementioned, but is at present only in possession of the waters of the Dhuis, and the water-wheels for the supply from the Marne, at St. Maur; even these last are in an unfinished state, so much time having been wasted, in consequence of the opposition of the proprietors of water privileges, and from the delays of the law. It is calculated that these causes will only affect the completion of the supply from the sources of the Dhuis and the Marne for about six months longer, and that then, at the period of the greatest want of water, the following supplies, in addition to those now at command, will be available:—

		Gallons.
From the aqueduct of the Dhuis .	. per day	5,538,720
From the machines of St. Maur .	. „	4,465,600
„ „ Trilbardou	. „	4,465,600
	Total .	14,469,920

The water expected to be brought by the aqueduct of the Vanne is not to be counted upon for the supply of the town for some time to come; and the further contributions from the springs of the Dhuis and the Surmellin, and from the Marne, must be considered to be eventual. It is, however, proposed to abandon the use of the springs on the north side of Paris, as soon as the waters of the Dhuis and the Marne can be substituted for them. And, from the tenour of the reports presented to the Conseil Municipale, it would seem that the authorities do not approve of the system of raising water by machinery from the Seine, as is now done to a great extent. It may, therefore, be supposed that the portion thus furnished will cease as soon as possible; and that the quantity of water that the city will have to dispose of, in the course of next summer, will only be about 47 million gallons, for the supply of a population of 1,667,841 souls. It is calculated that in future, and when all the works are executed. The following quantities may be distributed, estimating the amounts derived from the various sources at their highest values, or somewhat more than has been previously stated:—

From the present sources	40,636,960
The aqueduct of the Dhuis and the Surmellin .	8,931,200
„ „ Vanne	22,398,000
The mills of St. Maur of Trilbardou and of Les Isles Méldouses	20,793,600
The Artesian wells	6,698,400
Total . . .	105,388,160

This would constitute an ample supply for the wants of a much larger population; but it must be borne in mind that the waters of the Canal de l'Ourc would still constitute more than one half that quantity; and as this canal serves also for navigation, it is exposed to the various sources of impurities always attending such a use. Its waters, together with those pumped from the Seine, are intended for street washing, and for the monumental fountains; in fact, there are to be two sets of pipes, one to supply spring water from the Dhuis, the Marne, and the Vanne; the other, the waters of the Ourc, and the Seine, for the purposes of the municipality.

At the present time the number of pumps used by the city of Paris for raising water from the Seine, is seven; three are situated above Paris on the course of the river, at the port à l'Anglais, the quai d'Austerlitz, and les Maisons Alport; and the other four are at Chaillôt, Auteuil, Neuilly, and St. Ouen. These are set in motion by twenty-two steam engines, having a collective force of 1,000 HP.; but it has been decided that ten of the engines shall be sold as soon as the waters of the Dhuis can be distributed. Of the remaining twelve, the Chaillôt engines, which are upon the Cornish plan, with plunger pumps, are of 360 HP., and those of the quai d'Austerlitz, upon the double cylinder principle, introduced by Mr. Simpson (Past-President, Inst. C.E.), are of 240 HP.

The water taken from the Seine undergoes no filtration where drawn from the river, and retains all the impurities contracted during either the seasons of flood, or of drought. An inconsiderable quantity is, however, filtered at the 'fontaines marchandes' in the interior of the town, whence the 'porteurs d'eau' derive their supplies, and the revenue from this source is an important item in the receipts of the waterworks; in the course of last year it was equal to about one seventh of the total amount of the sum received for the sale of water.

In addition to the above works, there are the aqueduct of Arceuil, 13,235 yards in length; the Canal de l'Ourc, 106,788 yards long, which derives its waters from the River Marne, and arrives in Paris at the Bassin de la Villette, on the right bank of the Seine; the aqueduct 'de ceinture,' and the aqueduct de St. Laurent, of the united lengths of 4,730 yards.

The number of reservoirs at present in use is fourteen; of which four are for the waters of the Ourc, situated respectively at 66 feet, and at 86 feet, above the level of the Seine; nine are for the stowage of the Seine waters, at various heights, ranging between 151 feet, and 356 feet, above the same datum; and one is for receiving the waters of the aqueduct of Arceuil. It is proposed to abandon the last-named reservoir, and those that now serve for the Seine water, on the completion of the new works; but, in the mean time, the city has completed the construction of the reservoirs at Menilmontant, and at the telegraph of Belleville. These are, as has been before said, intended to receive the water of the Dhuis, and of the Marne; and are calculated to hold, together, in the two stories of arches, about 29,500,000 gallons. The cubical contents of the existing reservoirs are about equal to 22,823,000 gallons, a capacity insufficient to regulate the supply, especially when the deficient nature of the machinery used for the distribution of the water is taken into account. It is to be observed that this calculation of the quantity capable of being contained in the reservoirs of the town, does not include that of the Basin de la Villette, at the extremity of the Canal de l'Ourc.

The principle upon which the reservoirs of Passy, and of Menilmontant, are constructed merits further notice. That of Passy is intended to receive the waters pumped from the Seine at Chaillot, and those furnished by the Artesian well of Passy, when disposable; it is composed of three compartments, two of which are covered by a second range of arches, the third, intended as a reserve in case of fire, being deeper than the rest, and only of one story; the two upper ranges of arches, also, are made to hold a supply of water, one of them being covered and the other not. The united capacity of these various compartments is 9,227,097 gallons, and their levels above the Seine are repectively arranged at 150 feet, and 163 feet, above zero of the scale of the bridge of la Tournelle. The capacity of the separate reservoirs is, for those nearest to the ground, respectively 2,232,800 and 2,344,984 gallons; these are covered with reservoirs of the capacity of 1,282,792 and 1,495,729 gallons; and the uncovered side portions of the reservoir are devoted to the remaining 870,792 gallons. These buildings are formed on 'the tuf du calcaire lacustre,' which afforded a hard, resisting foundation, and did not require any particular precautions to prevent the subsidence of the piers, or to secure the watertightness, or the impermeability of the bottom. The external walls have been in consequence carried down to the depth of 8 feet 4 inches, and have a width of 8 feet 8 inches, all round. The floors are of masonry, 1 foot thick, in meulière and cement, covered with a rendering coat of 1¼ inch of the same cement worked to a fine face. This is covered with a range of cylindrical vaults of 10 feet opening, springing from pillars 2 feet 8 inches square upon the top, gradually enlarging to 5 feet at the bottom. It is calculated that in no case does the weight brought upon a square inch of this masonry exceed 152 lbs. The thickness of the arch forming the roof of the first tier, and the floor of the second division is about 1 foot 2 inches on the crown; that of the roof of the upper division is only 4½ inches, executed in two courses of tiles bedded in cement, and 'rendered' with a coating of that material, and covered with concrete.[1] But all the skill and attention of the French Engineers have been employed in vain, in the attempt to prevent the action of the atmosphere upon the masonry; and there are serious grounds for uneasiness, owing to the contraction and expansion produced by that cause. It may be, that the perfection of the setting of the cement upon the masonry, has something to do with this effect; it cannot yield like an elastic substance, such as mortar of the proper quality of hydraulic lime.

The reservoirs of Menilmontant are considerably larger than those of Passy, and, being founded upon the upper members of the Paris Basin, special precautions were required to insure that the ground should not yield under the combined pressure of the masonry, and the 29¼ million gallons of water intended to be stored. The marls covering the gypsum, of which the mountain of Menilmontant is composed, were not considered to be able to withstand that weight. The foundations of the piers were therefore carried lower down, and thence built in a description of rough rubble of meulière set in hydraulic lime. The bottom floor of the reservoir is arched over these piers, and the upper tier of arches rests upon this floor. There are two tiers, one to receive the waters of the Marne, and the other the waters brought in by the aqueduct of the Dhuis; both of these reserves are covered with groined brick arches, springing from square piers. The reservoir of the telegraph, at Belleville, is constructed in precisely the same manner; except that it is entirely above the ground, whilst the Menilmontant reservoirs are sunk in the hill side. The Engineers adopted a simple, but effectual, mode of protecting the marls, which are hard when originally cut, but which yield under the influence of the weather. It consisted in 'rendering' the surface of the excavation with a coating of plaster of Paris, of about 1½ inch or 2 inches in thickness. This was found quite sufficient to prevent disintegration, under the effects of rain, or frost. The height provided, as a variable head on the mains, was, in the Menilmontant reservoirs, above 15 feet, on the average; it was less in the upper reservoirs of Belleville, and greater in the lower reservoir of the waters of the Marne. The engine for raising the waters from the reservoir at Menilmontant to those at Belleville and Montmartre, is being prepared and will shortly be fixed. It is on the double cylinder, fly-wheel principle, similar to that at the Port à l'Anglais.

To secure the effectual distribution of the water, the city has at present 1,051,859 yards of pipes laid in the various streets and places, their dimensions ranging from 3 feet 8 inches, down to the service mains of 3 inches. These supply the 'fontaines publiques,' where the inhabitants are allowed to draw water gratuitously, and where the discharge is either continuous, or intermittent, and regulated by a species of spring button, held back while the water is flowing. In old Paris there were 46 fountains, where both the water-carriers and the public were allowed to draw water; 39 were of the kind just described for the use of the public, and from which the water-carriers were expressly forbidden to take their supply; and in the course of last year the authorities had placed 100 of these 'fontaines à répoussoir,' in the new districts of Paris. The gutters are washed out twice a day, a system which consumes a large quantity of water, but which is necessary, from their being the receptacle for what, in London, is disposed of in the dust bins. It is effected by 1,041 bornes fontaines, water-posts, whence the public may also draw for two hours in the course of the day, and by 2,144 'bouches sous trottoirs,' or plugs which discharge a little above the level of the foot-pavement. This service is complete in the ancient districts of Paris, but it is still defective in the new parts recently annexed to it. In addition to these, there are 741 stand pipes, from which the watering carts are filled; 70 for the service of the cabs and public conveyances, 118 other supplies, and 31 establishments where filtered water is sold, to be retailed at the rate of 5 centimes per pail, the vendors paying at the rate of 2 centimes. The quantity of filtered water, however, rarely exceeds 450,000 gallons a day. The monumental fountains, which add so much to the beauty of Paris, are about 54 in number; but the service of these is now very incomplete. At present the Bois de Boulogne consumes about 4,460,000 gallons of water per day; the Bois de Vincennes about 160,000 gallons; and the Parc Monceaux and the squares a variable quantity, that may be taken at 2,500,000 gallons per day. The tendency of the recent improvements of Paris, it may be added, is greatly to increase the quantities that are required for ornamental purposes, as new boulevards and parks are being formed in all directions.

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[1] Full details of this work may be found in the "Annales des Ponts et Chaussées," for the months of July and August, 1859.

The total quantity of water per day thus necessary to distribute in Paris, almost the whole of which would be supplied to the inhabitants gratuitously, is, therefore, as follows, calculating the quantities delivered by the 'fontaines à repoussoirs' and by the 'bornes fontaines,' or the 'bouches sous trottoirs,' at about 4,600 gallons per day each:—

	Gallons.
Bois de Boulogne, per day	4,500,000
Bois de Vincennes ,, ...	3,250,000
Squares and parks ,, ...	2,300,000
Monumental fountains ,, ...	22,328,000
The other fountains, the stand-posts, &c. .	19,099,000
Total, per day .	51,477,000

To this must be added 2,500,000 gallons supplied per day to the Government offices, and to the offices of the town and department, &c.[1] In other words, the city of Paris undertakes to deliver gratuitously the total quantity of 54,000,000 gallons per day.

The execution of the works required for the distribution of the water to the private consumer has been undertaken by a company, "La Compagnie Générale des Eaux," which accounts to the city for the sums due to it on account of the said works, and for the water rates. This species of partnership was approved by the Emperor in a decree bearing date, October 2nd, 1860, and limiting the duration of the company to fifty years; after the expiration of which term the city would enter upon possession of all the plant, buildings, and real property of the company. In pursuance of this agreement the company will receive all the water the town has to dispose of, and will supply it to private houses and factories, delivered at such heights as the pipes can command, at prices which have been settled, and which are specified in an official copy of the contract. It consents to account to the town for all the sums collected for the execution of the works, and for the rating, taking upon itself the risk of not being repaid by the consumers; and it retains, in compensation, the profit arising from the execution of the works, at a fixed schedule of prices, and at a sum that was at first agreed upon as a just remuneration for the trouble and risk. Thus, the company undertook the management, and the collection of the revenue, connected with the distribution of water in the old part of the town. This produced annually the sum of 1,850,000 francs, and the subscriptions from the suburbs were 1,750,000 francs. It was calculated that out of the above sums the company was entitled to the amount of 1,160,000 francs, as net profit and to 350,000 francs, the profits on the works, so that the city of Paris receives the difference between the sums of 1,510,000 francs, and 3,600,000 francs; and it shares the profit that the company makes beyond that amount, in the proportion of 75 per cent. to the town, and 25 per cent. to the company.

On the 31st December, 1863, the account for the water disposed of by subscription to the house proprietors, or the conductors of industrial establishments was as follows:—The quantity supplied from the canal de l'Ourc was estimated to be 6,625,408 gallons per day; that from the Seine, or other sources, such as the well of Grenelle, the aqueduct of Arcueil, &c., was estimated at 4,635,516 gallons also per day. But the town, in fact, delivered much more than these nominal quantities, as the waters of the canal de l'Ourc were dealt with on the constant-supply system, and without any kind of check upon the consumption. Indeed, M. Belgrand estimated that the quantity of water thus delivered was nearer 17,000,000 of gallons. The actual receipts for the private supply by the 'Compagnie Générale,' to the 31st December, 1864, are 3,822,760 francs; this sum was received from 23,074 subscribers, and it was calculated that these would increase in about the proportion of 2,000 in the course of twelve months. This is but a small number, when compared with the houses in Paris, which may be estimated at considerably more than 50,000; and it may be cited as a proof—were such wanting—of the bad effects that the gratuitous system must always produce upon the daily life of the citizens. Is it to be expected that the house proprietors would incur the expense of laying on the water to their tenements, when the occupiers can obtain an unlimited supply from the street fountains for the mere trouble of seeking it? The intervention of the company is, however, found to be advantageous to the interests of the town; because the latter has, in this manner, secured the services of a body of men who have a direct interest in every subscription registered.

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[1] These comprise the prefecture of the Seine, and the city of Paris; and the bureau de l' assistance publique, comprehending the hospitals, workhouses, and prisons.

The city has also ceded the filtering fountains in the various parts of the town. The company therefore receives the payment from the water-carriers, who, in their turn, charge the house proprietors and lodgers for the supply thus brought to their doors. At the present day the price charged to the carriers is at the rate of about 9*d.* for 230 gallons, and the retail price is 4*s.* for that quantity. It was considered that the increase in the price constituted a more serious grievance, as the poorer classes are in Paris the largest consumers of the filtered waters of the Seine; and this was one of the principal reasons brought forward to justify the great outlay undertaken for leading to Paris the spring water from the Dhuis and the Vanne. Up to December 31st, 1863, the receipts from the 'fontaines marchandes' were 668,181 francs which, added to the sum received from the subscriptions, 3,822,760 francs, made a gross total of 4,490,941 francs; thus showing that the city imposes upon itself a heavy burthen to gain what is, after all, a very deficient supply. Owing to the feeble pressure upon the mains, and to the prevalent habit of letting out the tenements in flats, so that the house proprietors have no possible control over the water, it is seldom that the service is delivered at a greater height than the first floor—thus the gardens and stables can command a supply which is unattainable by dwellers in the attics. No doubt it is to this fact that much of the unhealthiness, and the high rate of mortality in Paris are to be attributed.

Moderate as are the salaries allowed by the French administration, the sum paid to the assistants of the engineering service, appears as a considerable item in the municipal budget.[1] That sum was for the year 1864, £82,400—divided as follows:—

	£.	s.	d.
Salaries specially devoted to the service of the waters .	10,600	0	0
Maintenance of the hydraulic establishments	22,600	0	0
Coal, maintenance of large engines, oil, tallow, and heavy repairs	35,200	0	0
Paid to the Compagnie Générale des Eaux, as their charge for 'frais de régie'	14,000	0	0

It is to be observed, however, that the town authorities generally effect a saving of about £4,000 per annum in the amount put down for coals.

Upon a careful review of all the conditions of the Paris water supply, it seems to the Author, that it must be looked upon as a commercial failure; for the town, while paying 2,060,000 francs for salaries and repairs, derives only 4,750,000 francs from every source of revenue, including the interest and sinking funds. A more generous view of the question has, however, been adopted by the authorities of that city, and it may fairly admit of doubt whether the system can be deemed entirely unsuccessful, if considered as a means of meeting the wants of those who are too poor to pay the rates that would be required for conducting the water to their doors. Yet, it must be admitted, that the principle is essentially faulty, inasmuch as the scheme entails upon the city a heavy expense, which no one has a direct interest in checking, because it is defrayed out of the town dues, instead of being made a separate charge upon the funds of the city, which would be, sooner or later, obliged to present something like a balance; and it must also be confessed that the great promises made in the years 1858, 1859, and 1860, have hitherto been but partially realized. But apart from the false principle on which the Paris waterworks are arranged, and from the disappointment, and consequent delay that has attended their execution, the details of the plan are characterized by a singular amount of skill, and unity of purpose, and do the greatest honour to M. Belgrand. After the labour of nearly fifteen years, at length his resolution, patience, and perseverance have been rewarded, by the adoption of the measures he has so energetically advocated, and which he has succeeded in bringing to a practical result.

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[1] In addition to the numerous staff employed by the Compagnie Générale des Eaux, there are in the service of the city, an Engineer-in-Chief with six clerks, and frequently more; an ordinary Engineer who, under the Engineer-in-chief, is charged with the inspection and maintenance of the machinery, with eleven men; and an Inspector, who has under his orders twenty-eight men, twenty of whom are reserved for the arrondissements. There are also one hundred and five men whose duty it is to attend to the monumental fountains, and street supplies; exclusive of fourteen men who superintend the maintenance of the basins and reservoirs. The new pipes that are to be laid come under the superintendance of the eleven ordinary Engineers employed in the paving service, who, in this case, act under the orders of the Engineer-in-chief.—G. R. B.

Mr. G. W. **Hemans** said, he gathered from the Paper that the daily water supply for the whole population of Paris, amounted to only 21 gallons per head, and that more than one-half of that total supply was devoted to public purposes, in such a manner that a great quantity ran to waste. If he were not mistaken, as much as 54,000,000 gallons per day were bestowed upon the public fountains and conduits of the city, and if that quantity were so applied, the proportion utilized must be much below the supply furnished to other great cities, and the scheme must be considered to be an instance of failure.

Mr. **Vignoles** said, the Institution had been indebted to the Author on several occasions for bringing forward interesting subjects, of which this was not the least. He remembered former instances, in which Mr. Burnell's assiduity and attention to particular points of foreign engineering had given rise to very profitable discussions. The point which most struck him in connection with the present subject was the leading fact, that with a limited supply of water, one half went for ornamental purposes, at the expense of the public health. All the poorer classes of Paris, who inhabited the upper stories of the houses, were imperfectly provided. It was the same in other towns on the Continent, great displays were made in fountains and embellishments, while the health of the community was neglected; and that must be the case where the government attempted to do everything, and where a spirit of self-reliance was wanting. He considered the water supply of Paris at present a failure, and he was glad that the Author had stated it to be so, commercially, though successful as an engineering operation.

Mr. **Robert Rawlinson**, C.B. remarked that the question of water supply was of the utmost importance, and he would preface the few remarks he proposed to make, by stating that it behoved speakers in this Institution to consider carefully the force of any words they used; because, to the credit of the Institution be it said, the opinions of its members on questions of engineering were looked to by foreign nations, and the technical laws laid down were attempted to be carried out by foreign peoples; and, consequently, if false notions were promulgated, mischief would result in other quarters, just as the enunciation of true principles was calculated to do good. The water supply in Paris appeared to be similar to that in London. In both cases water was drawn from various objectionable sources; for London the principal one being the Thames, and for Paris, the Seine, and in the case of Paris from below the city, where the water was necessarily impure. French engineers, and he supposed he might also say French medical men, appeared to have arrived at the erroneous conclusion, that water which contained 16 degrees of hardness, or 16 grains of bi-carbonate of lime per gallon of water, was more wholesome than purer water. That doctrine had also been promulgated in this country, but it had also been most earnestly controverted. To take a practical view of the matter, those who had to study animal life, and whose duty it was to develop it to its highest degree of perfection, looked upon hard water as poisonous; for instance, a trainer of race-horses would not attempt to get an animal into racing condition with water of 16 degrees of hardness, experience having taught him that such a course would end in failure. Horses must be trained on soft water, and care must be taken not to change the source of supply. In the town supplies of this country there were many examples, on a great scale, that soft water was not injurious, but the contrary. Glasgow was supplied with the soft and very pure water of Loch Katrine; then there were Manchester, Whitehaven, Keswick, Lancaster, and other places, as Falmouth, having very soft water below 4 degrees of hardness. In fact, hard water, far from being necessary to human health, was, if possible, to be avoided. He believed a great amount of mischief was done by invalids drinking hard water, as there was scarcely a watering-place along the eastern and southern coasts of England, from Scarborough to Brighton, which was not supplied with hard oolitic or chalk water.

With regard to quantity, Paris and London appeared to be similarly provided. The latter, with its population of 3,000,000, was supplied with about 100,000,000 gallons per diem, and Paris, with a population of about 1,600,000, had a supply of nearly 50,000,000 gallons per diem. In both cases, however, much of the water was wasted. Public companies and free institutions in this country were supposed to do a great deal better than the Imperial Government of France, but he was sorry to differ from that opinion. He must express his belief, that if the two cases were fairly and fully analysed, mismanagement and great waste of water would be found both in London and in Paris. In the ornamental fountains of Paris, an enormous quantity of water was wasted, while the poor in their houses were left to starve. In London, through mal-administration, defective services, and other causes, a waste was permitted of probably one-half or even two-thirds of the water brought in by the companies. He had seen valves and stand-pipes leaking for months together, causing the loss, in some instances, of as much water as would have supplied a small district. Throughout London the supply was intermittent. Frequently the ball-cock was unscrewed and the service was left open, so that every time water was turned on large quantities ran down the overflow-pipes and into the sewers. The water was supplied in the east of London by stand-pipes having no taps, it was not taken into the houses; and the complaint was that the poor in London, like the poor in Paris, were destitute of water, and yet the daily supply to London and Paris was said to be upwards of 30 gallons per head, men, women, and children. The only true method of giving a supply, was to carry a service-pipe and tap into every building; but to do that the supplies to houses in London and Paris must be organized on a different principle to any yet attempted. In the existing mains there was a pressure active, for injury, of something like 100 or 200 feet, while the pressure for useful service was not more than 3 or 4 feet. The water, when drawn from the street and used for fire service, would not rise in many places 3 feet from the pavement, because the great lengths of mains and the friction destroyed the head. Up to a recent period in London, for fire service, the old, effete method of a plug driven into the main was the only one in use, and that plug had to be drawn, to allow of the insertion of the stand-pipe before the engines could be supplied. Neither London nor Paris could have an efficient and constant service without the intervention of service reservoirs. The two-storied reservoirs in Paris, as described in the Paper, he had no hesitation in saying, without seeing the section, would be difficult to execute, difficult to maintain in an efficient state, and must have been exceedingly expensive, and in his opinion were not worthy of imitation. It was stated that the fall of the new aqueduct to bring water into Paris, was 1 in 10,000. The fall of an aqueduct must be in proportion to the depth and volume of water which it had to deliver. The fall of the New River in London was 1 in 10,000, or about 6 inches to the mile; but with so large a volume and an unpaved channel it was necessary to form a weir and give the water a vertical fall of a few inches at certain points of its course. He found that plan was adopted in the East. In laying out a line of aqueduct two principles were involved. If it were graded, as the Romans graded some of theirs, from 5 feet to 15 feet per mile, there would be difficulty in stopping the water at any point. It was practicable, however, to grade an aqueduct having a fall of 15 feet or 20 feet per mile, if vertical falls were introduced at intervals, alternately with level or nearly level lengths. This mode enabled an Engineer to fix the velocity, so as to prevent undue 'washing.' The vertical falls tended to aërate the water, and this in itself constituted an additional advantage. All covered aqueduct conduits should be abundantly ventilated; and there should be side entrances, stop-gates, overflows, and washout-valves.

Rev. J. C. CLUTTERBUCK would not attempt to follow the Paper through all its details; but there were two points on which he would offer a few remarks. One was the partial supply from the Artesian wells, and the other, the way in which the French

Engineers proposed to augment the flow of water from the head sources of the rivers. First, as to the supply from the existing Artesian wells; the way in which the Grenelle well at Paris was carried out by M. Mulot, at a heavy expense, and under serious discouragements and difficulties, was a matter of history.[1] The other great work at Passy had not long been completed.[2] Those who were well informed as to the state of things, admitted that the Grenelle well was affected by the discharge of water from that at Passy, to a certain extent. It was to this fact he wished to draw attention. He ventured to remind the Institution that in his published letter to Sir John Sebright in 1841,[3] he said, "There is reason to believe that a practice which has lately obtained of sinking wells into the chalk in London for the use of large establishments, may, if extended, produce serious consequences." Though this statement was received with incredulity at the time it was made, and though, in Papers, read at the Institution in 1842 and 1843,[4] similar statements were made, and were called in question, it was demonstrated in a Paper read in 1850[5] that those anticipations were correct. Since then the supply from that source had been given up by many large breweries and other establishments, and recourse was again had to the water companies, except in some cases for the purposes of refrigeration. Though the well at Grenelle derived its water from the lower green sand, the same principle might be applied to both cases, and he had been able to calculate the height to which water would rise in the Artesian wells of the London Basin, viz., the mean between the highest source of supply, and the ultimate outfall. He applied the same rule to the Paris Basin, the extreme points being the height of the water in the green sand at Lusigny, and the sea level at Havre; the rule stood good, and a line drawn from Lusigny, 131 mètres above the sea, and 100 mètres above Paris, gave the exact height that the water rose at Grenelle, and also at Elbeuf. He mentioned that fact, because, if, as had been observed, what was spoken in that room went all over the world, he would seriously warn those interested in the two wells in Paris, to which he had referred, not to draw too freely on the source whence their water was derived, viz., the lower green sand. A most extraordinary well, the Warren well, had been sunk to the same stratum near Brighton. He had calculated the height to which the water would rise, and had expressed an opinion that no great quantity of water would be found; the facts confirmed his anticipations. Judging from what he had seen of the yield of water in the lower green sand in England, which corresponded, geologically, with that of the Paris Basin, he believed the present supply would be endangered if any large demand was made on it by boring additional wells. His anticipations, expressed twenty-five years ago, had been realized as to the wells sunk into the chalk in London; and if the advice he now gave as to the wells sunk into the green sand at Paris was neglected, the same disastrous effects would be realised there also. In all cases he had protested against any tampering with underground water, especially at the sources of rivers, as was proposed, for instance, in the project for supplying Cheltenham with water, from Cerney, on the Upper Thames. As he understood from the Paper, the French Engineers contemplated an increase of flow to the rivers supplying Paris, by some operations at their sources. That he considered a most dangerous experiment; it would produce the effect which, he feared, might now be traced to land drainage, especially in the oolitic formations of the watershed of the Upper Thames, where thin seams of oolitic rock alternated with beds of clay. Where those beds were drained for agricultural purposes, the water, instead of oozing from the hill sides throughout the year, was carried at once into the river, and reduced its perennial volume. He hoped that the Engineers, as the guardians of the water of England—for so he regarded them,—would do all they could to discourage any such interference with underground sources of water, but would be content to take it when it appeared above ground, as that course, he believed, would tend to the economy of the water supply of England, the value of which was daily increasing, and which, if once injured, could never be restored.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxiii., p. 459.

[2] *Ibid.*, p. 460.

[3] *Vide* "Letter to Sir J. Sebright, Bart.; On the Effects which will be produced by taking a supply of Water to the Metropolis from the Valley of the Colne, by the proposed London and Westminster Water Company." Tract, 8vo., vol. lxxviii. Watford, 1841.

[4] *Vide* Minutes of Proceedings Inst. C.E., vol. ii. (1842), p. 155, and (1843) p. 156.

[5] *Ibid.*, vol. ix., p. 151.

Mr. JOHN MURRAY said, respecting the fall and length of the New River, that from its source at Chadwell Spring near Ware, to the 'head' in the parish of Clerkenwell, the length was originally about 39 miles, and the fall throughout was, on an average, about 4½ inches per mile. There was originally, and now existed, a stop-gate at Bush Hill, to regulate the sudden fall, which varied at that point, in recent times, from 18 to 24 inches. The opening of the sluice varied from 15 to 18 inches in height, and it was 4 feet 6 inches wide, discharging, by calculation, about 3,100 cubic feet per minute. A great number of bends, some of them very circuitous, originally existed in the course of the river, as it followed the contour of the country. Many of those had been taken off, by making the channel straight, through cuttings, and by embankments; and he believed the course had been shortened by these means about 6 or 7 miles. In consequence of the shortening of the distance, the fall had to be regulated, otherwise it would have been in some places too great, and would have torn up the bottom, or injured the banks. For that purpose two additional stop-gates had been provided, one at Hornsey, and the other at Highbury. The fall of the water surface, deducting the stop-gates, varied from 3¾ inches to 4 inches per mile. Those stop-gates acted as regulators at certain periods; for, by partially closing the openings of the gates, the water accumulated in the pens above, and then, by raising the gates to their ordinary height, the extra body of water was allowed to pass along the channel to the reservoirs at Stoke Newington and the New River Head.

Mr. W. Atkinson remarked, it had been stated that in laying out an aqueduct there was an advantage in constructing a great portion of it on a flat gradient, and in acquiring the velocity by the introduction of rapids at different points of the course. In the canal of Isabel II., from the Guadarama range to the city of Madrid, the gradients, in open cutting and earth-works, were 1 in 5,000; in tunnels 1 in 1,500; and for aqueducts 1 in 1,000. The object in that was to reduce the cost of the works by increasing the velocity, and diminishing the sectional area. The same plan had been adopted in the Canal de Marseille, at the celebrated bridge aqueduct of Roquefavour, where the sectional area was reduced one half; and the velocity, by the increase of gradient to 1 in 250, was doubled. Great stress had been laid upon the benefit of supplying towns with soft water, on the ground that hard water for drinking purposes was not equally conducive to health. But a high authority on that subject, Professor Johnston, had expressed an opinion apparently at variance with that view. He had said:—

> "It by no means follows in all cases, perhaps not even in the majority, that the purest of water is the best for the health of a given family, or for the population of a given district.
>
> "The bright, sparkling, hard waters, which gush out in frequent springs from our chalk and other limestone rocks, are relished to drink, not merely because they are grateful to the eye, but because there is something exhilarating in the excess of carbonic acid they contain, and give off as they pass through the warm mouth and throat, and because the lime they hold in solution removes acid matters from the stomach, and thus acts as a grateful medicine to the system. To abandon the use of such a water, and to drink daily in its stead one entirely free from mineral matter, so far from improving, may generally injure the individual or local health.
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> "The human body requires a certain proportion of lime to be contained in or mixed with its food. If the common diet do not contain a sufficient proportion of this mineral ingredient, the common water of the country may supply the deficiency; and thus a national mode of living may spring up, the salutary properties of which depend partly upon the food, and partly upon the water."

If the question of absolutely pure water, with regard to its distribution in houses, were considered, the effect of the water on the lead must be taken into account; for, though lead cisterns were not much used, lead service pipes were generally employed. Lead in small pieces, when placed in distilled water, was rapidly dissolved: it was established by eminent chemists, that where lead pipes were used, the most dangerous impregnation was when the water was the purest, and that so large a proportion of salts as a 4,000th part would be insufficient, if those salts were chiefly chlorides. Now, the 4,000th part was about 17½ degrees of hardness, and was nearly the same as the standard of the French Engineers. So that, whether the question was viewed physiologically or with regard to the danger from solution of lead, it did not appear advantageous to use very soft water.

Mr. J. F. Bateman thought the necessity for the presence of carbonate of lime in water, for the purpose of preserving health, was far from being proved. The great characteristics of the people who inhabited the soft-water districts of England and Scotland, were size of bone, and strength; whereas those who lived where there was the largest proportion of lime in the water were, in general, physically inferior. The people of the granite districts of Aberdeen, of the highlands of Scotland, those of the Silurian districts of the lowlands, and of the Lake districts of Westmorland and Cumberland, as well as the inhabitants of the backbone of England, between Yorkshire and Lancashire, drank soft water because they could get no hard; and they were among the finest men to be found in the kingdom; whereas in those districts in which there was abundance of lime in the water—Dorsetshire and Wiltshire, for example—the race was much smaller. He had hoped that the erroneous theory of chalk in the water being necessary for the formation of bone in the animal frame had been exploded. Again, there was the unfounded apprehension of the action of soft water on lead pipes being deleterious. The city of Glasgow had expended no less a sum than £4,500 to investigate that particular question. The water of Loch Katrine acted very powerfully indeed upon lead. On putting a piece of bright, pure lead into a vessel filled with it, its effects were seen in less than half an hour: the water became opalescent. It was declared that the health of the inhabitants of Glasgow would be seriously affected by lead-poison if the Loch Katrine water were supplied to them. But the water had been supplied without any apparent ill effects. He had in his possession, for twelve years, lead pipes through which the water of Loch Ness—which acted more powerfully on lead than that of Loch Katrine—had passed for fifteen or twenty years. Those pipes were completely coated inside with an oxide of lead, which was insoluble in water, firmly adhered to the pipes, and perfectly protected them. There was no doubt that at first, if the pipes were pure and bright when introduced into a house—an unusual condition—the water would, for a short time, act upon the lead, but the ultimate oxidation of the surface afforded an insoluble lining, and afterwards no further danger was to be apprehended. As to the effect of soft water upon the health of those who drank it, the town of Paisley was formerly supplied with water of a very hard description, and gravel and stone was the common malady among the inhabitants. Now that they had soft water that disease had disappeared. Manchester was at one time supplied with hard water, and during that period the same disease was prevalent there. Soft water was now supplied to that city, and beneficial results had followed. As an instance of the tendency of soft water to prevent, or destroy calcareous accumulation, he might mention, that when he first began to construct the Manchester Water Works, he found the whole interior, not only of the reservoir, but of the pipes—large and small—coated with myriads of small mussels. No doubt the material of which their shells were formed was derived from the lime contained in the water; for upon introducing soft water the mussels, no longer able to obtain the lime necessary to their existence, died, became detached, and were carried by the current of the water to the lower end of the pipes; many of the smaller pipes becoming, in consequence, choked with them. The effect was, that the soft water gradually dissolved the shells, and ultimately all were absorbed, and disappeared. During the process of absorption, the water delivered in the city varied from 1½ degree to 7 degrees of hardness; the variation being, no doubt, due to the presence of the mussels. Now the water was uniformly delivered in its normal state of from 1½ degree to 2 degrees of hardness. He believed there had been no case of lead-poisoning properly attributable to the soft water, in Manchester. In the older parts of the town there were, however, multitudes of lead cisterns deriving their supply from the rain falling upon the roofs of the houses, which were covered with the salts and acids issuing from the chemical works and tall chimneys of the neighbourhood. Those salts, or acids, being carried away with the water, acted powerfully upon the lead, and cases of poisoning were the result: but there were none where the water was conveyed in lead pipes directly from the street mains into the houses. He thought the importance of that branch of the subject was such that it never ought to be overlooked. The introduction of the Loch Katrine water into Glasgow produced an immediate saving in domestic establishments of £40,000 a year. In his own household, where he had introduced water of only $\frac{6}{10}$ths of a degree of hardness, in the place of the hard water previously used there, he calculated the economy at 5s. per head per annum. It was not hardness, but aëration and coldness which gave freshness and pleasantness for drinking. Those were the characteristics of the hard water from the old and new red sandstone, from the millstone grit, from the gravel detritus of granitic and most primary rocks; and of the soft water from the lower green sands. Where water had passed through the gravel or porous rock of such formations, it became aërated, and it was that, and not the lime, which made it so pleasant and wholesome. The same might be said of the Ennerdale water, and of that of the Lake districts generally. All those waters, with the exception of Loch Ness, were derived from the clay slate, or Silurian formations, which contained no lime. The clay-slate waters were exceedingly soft, but generally more vapid than many other waters. Loch Katrine water was much aërated. The water of Loch Ness was derived from the granite; and its more powerful action upon lead was attributable to the large amount of oxygen it contained, and the absence of lime. Pure, brightly-scraped lead, exposed in that water, would, in a few days, make the water look thick and milky, and yet it was drunk without the slightest injury to health.

Referring to the falls in aqueducts, he might state, that in the Loch Katrine aqueduct of the Glasgow Water Works, the fall was 10 inches to the mile throughout, except where the water was carried by syphon pipes across deep valleys which, in one instance of a hollow of 250 feet, was done for a distance of 3½ miles, and in these cases there was a fall of 5 feet per mile, to economise the size of the pipes. In the city of Paris, it would seem, that with only half the population of London, the anticipated supply of water would be greater than the latter city now had.

Mr. S. C. HOMERSHAM said, at the present time the inhabitants of Paris received, by means of the recently-constructed Dhuis aqueduct, a daily supply of 8,000,000 gallons of pure spring water, and he thought a greater boon could not have been conferred upon any city. Further, when the intended Vanne aqueduct was finished, another 22,000,000 gallons of the same kind of water would be conveyed to Paris. It was satisfactory to find, that M. Belgrand, the Engineer of the Paris Water Works, had succeeded in inducing the authorities to construct the Dhuis covered conduit 80 miles in length, in order to bring into the city pure spring water from the chalk, instead of taking the new supply from the River Seine, a short distance above Paris, and filtering it, as was once proposed. Commencing at a distance of about 60 English miles east from Paris there was an area of 4,780 square miles of chalk rising in hills, the tops of which were from 500 to 600 feet above the level of the sea. Not only was the rainfall of that district, or the greater portion of it, absorbed by the chalk, as it fell, but there was a large drainage ground at a higher level, and beyond it, having an area of about 9,500 square miles. So that the chalk not only received the rain-water that fell on its own surface, but also received and absorbed a portion of the water that fell upon those 9,500 square miles beyond it. Calculating, however, that a depth of only 10 inches per annum of the rain was absorbed on the chalk area, which was a reasonable calculation, there would be a supply of water into the chalk equal to one billion six hundred million gallons per day for every day in the year. He mentioned this because a hope had been expressed, by a previous speaker that the water of the chalk would not be tampered with; but Mr. Homersham knew, that at the point near where the Dhuis aqueduct received the spring water, 40,000,000, or 50,000,000 gallons per day of spring water might be obtained by underground works with the greatest ease, without injury to any interest whatever. At the present time, that water flowing through subterranean channels in the chalk escaped into the sea, and was wasted. If the proposition for taking the Seine water, filtered, had been carried out, the result would have been that the inhabitants of Paris would have had supplied to them water containing from 12 to 13 grains of saline or mineral matter to the gallon, whereas the water of the chalk contained 22 grains of saline or mineral matter; but in addition to the mineral matter, the Seine water contained a large quantity of impure organic matter and living animalcules. Even if the river water were filtered, first, through sand, and afterwards through a Lipscombe filter, the animalcules and the other impurities would not be removed, so that if the water were used without being boiled, it might cause many diseases. The avowed object of M. Belgrand was to get spring water, free from impure or organic matter.

With regard to the action of soft water upon lead, it was quite true that Loch Katrine and other lake waters dissolved lead; but that was not the case with pure chalk spring water when softened down by Dr. Clark's process to as low as 2½ degrees of hardness. The latter had no action of any kind upon lead; but lake and surface waters were never found to be pure; that was to say, although the inorganic, or mineral matter, might not exceed 2 grains or 3 grains to the gallon, yet, if an examination with the microscope were made, the water would be found highly charged with living animalcules, nourished by the impure organic matter contained in the water. It was that which made lake and river water dissolve lead and be so unwholesome. The Registrar-General's late returns showed that in Glasgow, which was supplied with the soft Loch Katrine water, the death-rate was as much as 38 per thousand; in Birmingham it was 30, and in Sheffield 33 per thousand; but at Hull, where, within the last two or three years, pure spring water from the chalk had been supplied to the town, instead of filtered river water, the death-rate, after the change, fell as low as 23 or 24 per thousand The examination of water was not merely a case for the chemist, but also for the microscopist and physiologist. A short time ago Mr. Homersham had the water from the lake of Orta, in the north of Italy, analysed; it was found to be only $\frac{6}{10}$ths of a degree of hardness, and to contain only 3 grains of mineral matter per gallon, but when examined with the microscope, it was found to contain many kinds of living animalcules, so that if taken it would undoubtedly prove noxious. At a lecture, recently delivered by Dr. Thudicum, before the Society of Arts, it was stated, that in the lake districts of Switzerand, the propagation of entozoa among the people was caused by eating fish taken from the lakes. If really pure wholesome water for domestic use was wanted, uncontaminated subterranean springs must be resorted to, and if the water was too hard naturally, it might readily be softened by artificial means. Chalk spring water might easily be brought down to 2½ or 3½ degrees of hardness. So treated, it was much approved for domestic use. It was not only soft, but did not contain any organic matter, and had no action on lead. The mud from the bottom of Loch Katrine, and from some large artificial reservoirs used for town supplies, would be found to be of the most disagreeable kind, being composed of decayed leaves, the exuviæ of fish, and other impurities, yet such lakes and the reservoirs were never cleaned out, and yet the water was supplied to towns for drinking purposes. He could refer to a reservoir at Todd's Brook, in Derbyshire, at the head of the Peak Forest canal. The water was of remarkable softness, and contained only 2 or 3 grains of mineral matter to the gallon. He had sent samples of that water to two eminent chemists, and each of those gentlemen required as much as 3 gallons to make a reliable qualitative analysis. Notwithstanding this, he had frequently taken a tumblerful of that water direct from the reservoir in the autumn, and had counted in it, without the aid of a magnifying glass, twenty different living insects. It was said that such water should be filtered. The larger insects might be removed by filtration; but the smaller ones, together with their eggs and larvæ, and other impurities, would go with the water through a sand filter, first, and then through a Lipscombe's filter, and afterwards the organisms would still live, breed, die, and putrefy in the water. He therefore thought the authorities in Paris had done wisely in acting upon M. Belgrand's advice, and in going the long distance of 80 miles with one conduit, and 105 miles with another, to obtain spring water from the chalk hills, instead of taking their supply from the River Seine, or from other surface water. The Dhuis spring water could be easily reduced to about the hardness of 2½ degrees, if that was required. As to the wholesomeness or unwholesomeness of chalk dissolved in water, he believed it was of little consequence whether there was lime in the water or not; but he held it to be indispensable that water for domestic use should be free from all organic impurities.

Mr. C. B. LANE said, that a quarter of a century ago it was proved from statistics, by the late Dr. Prout, an eminent chemist and physician, that calculous diseases were more rife in the districts of England where chalk-water was drunk than in others.

Mr. FLEEMING JENKIN remarked, that this Paper was one of peculiar interest to him, inasmuch as he was engaged, with Mr. Forde, in carrying out water works of considerable extent in the town of Rouen. The method of supplying the private consumers in Paris had not been touched upon; it might therefore be interesting to the Institution to be informed of the system pursued in most French towns. There were no water rates in Paris, or in any other town in France; but the water was subscribed for, and the charges were based upon two plans not in use in England. One might be called the gauge-cock system, and the other the system by estimation. By the former plan the water, where it went into the houses, was regulated, so that the average pressure on the pipes would not deliver more than a certain quantity per day, which quantity was taken as the basis of the subscription. Thus, if a subscriber wished for 1 cubic mètre of water, or 220 gallons per diem, the cock by which the water was supplied was 'throttled,' so that if the water ran into the house the whole day, he could not get more than the 220 gallons subscribed for. Besides this, there was a cistern with a ball cock, which shut off the water when full. Under that system much waste was prevented. That was the plan proposed to be adopted in Rouen, and actually used in most other large towns in France. By the other system it was estimated that a certain quantity of water was consumed per day, on the following scale:—

	Gallons.
For each person	4·4
„ horse	16½
„ two-wheeled carriage . . .	8¼
„ four-wheeled carriage . . .	16½
„ square mètre of garden . . .	⅓

In Paris, the price for filtered water ranged, from 2*s*. 4½*d*. per 1,000 gallons for small subscriptions of 55 gallons per diem, to 1*s*. 2½*d*. per 1,000 gallons for large subscriptions of 220 gallons per diem. The water from the canal de l'Ourc was charged for at the rate of 7¼*d*. per thousand to subscribers who took quantities of between

220 and 1,100 gallons per diem. For very large quantities it was supplied at 4¾*d.* The smallest subscription allowed for domestic purposes was £2 8*s.* In Havre, the arrangements were very similar; the price ranged between 19*s.* 9*d.* and 11*s.* 3*d.* per thousand; and the smallest subscription was £2 per annum. In Bordeaux the subscription might, at the option of the subscriber, be based on the rent, being about 6½ per cent. on small rents (£12), and a little more than 1*s.* per cent. on large rents, the smallest subscription being 16*s.* There were no means of ascertaining what proportion of the supply to Paris was reserved for the use of private consumers; nor could he find out what the consumption was at the present moment. At Rouen the authorities stipulated for a supply of 30 gallons per head per day; reserving to themselves the right to use one half the supply for municipal purposes, and of that quantity very little was employed for ornament. The water was allowed to run along the gutters for two hours a day in each street; but as this was done at a low velocity, it did not carry away much dirt, and seemed almost to be wasted.

Mr. **Bateman** observed, that in refuting the opinion, that hard water was essential to health, he had instanced the soft-water districts as producing the finest men, merely to show that soft water was not prejudicial to the formation of bone. He agreed that the hardness or softness of water had nothing to do with the disease of gôitre, which was attributable to the close air of the valleys. With respect to the death rate of 38 per thousand, in Glasgow, he would say, in the town of Whitehaven, which was now supplied with water from the Ennerdale Lake, in the four years preceding the introduction of that water, the death rate was 36 per thousand, while in the four subsequent years it was reduced to 24 per thousand, and there was no other cause to which that diminution could be attributed but the introduction of the soft water.

Mr. **Hawksley**, V. P., remarked, that there was a sequel to that; for after the second period of four years, the death rate returned to what it was previously.

Mr. **Homersham** explained, that his meaning was, not that the softness or hardness of water had so much influence upon health, but that pure spring water was perfectly wholesome; while lake or river water was always found to be more or less impure, and in consequence abounding with minute insects.

Mr. G. R. **Burnell**, in reply, said he had little to add to the Paper. As regarded the present water supply of Paris, he thought it could not be counted upon. The proportion of the Paris water supply which was intended to be devoted to municipal purposes, and for gratuitous distribution, would be a minimum of about 52 million gallons, or about 50 per cent. of the calculated ultimate supply, which it was estimated would amount to 103 million gallons per day, or commensurate with the increase of the population. The question of the advisability of using hard or soft water had been sufficiently discussed, and he would not offer any remarks upon that point, further than that the instance so often quoted, of Aberdeen and that part of the coast, was a fallacious one, because the inhabitants of all that part of Scotland were of Scandinavian descent, and were therefore a large-boned race. He thought that the neglect with which questions of ethnology were treated might lead to great errors. The Registrar-General's returns of the deaths in those towns where soft water was consumed, as Liverpool, Manchester, and Glasgow, showed a considerably higher rate of mortality than that of London; that, he thought, might be taken *primâ facie*, as presumptive evidence in favour of hard water.

Upon the subject of the wells of Passy and Grenelle, he would say, when the Passy well was first sunk, it considerably affected the Grenelle well, so much so, that the yield of the latter fell off to about 120,000 gallons per day from its former yield of 200,000 gallons, and from its original yield of 800,000 gallons per day. The size of the bore of the Passy well was about 3 feet 4 inches, while that of the Grenelle well was only 8 inches: the yield of the well was, consequently, about in proportion with the size of the bore. The inference he drew from that was, that M. Belgrand had reckoned upon rather too large a yield from the proposed Artesian wells.

Mr. Fowler, President, said, as that was the last regular meeting of the Institution till November, he wished to say a few words as to the Papers which had not been read. The discussions during the present Session had generally extended to a greater length, and, he thought he might say, had been of greater interest than usual; but the consequence had been that a considerable number of Papers accepted by the Council had been obliged to be postponed. The list embraced many interesting subjects, and he believed there were other communications of equal importance in preparation; at the same time, he must be permitted to say, the Council would be happy to receive further essays on some of the many unexhausted subjects which were suitable for discussion. He would beg to add, that he remembered no period in which the Papers had been prepared with more care, or with more liberality of illustration, than in the present Session.

May 15, 1866.

JOHN FOWLER, President,
in the Chair.

His Royal Highness PRINCE ALFRED ERNEST ALBERT[1] was unanimously elected, by acclamation, an Honorary Member.

The following Candidates were balloted for, and duly elected:—JAMES MELVILLE BALFOUR, WILLIAM CLARKE, JAMES COLLET, HENRY WHEELER DAVIS, JONATHAN DICKSON IKIN, ALFRED MOORE, and WILLIAM SMITH, as Members; JAMES HENRY COTTERILL, CHARLES FOOTE GOWER, JAMES SIDNEY HARGROVE, JOHN GILLETT LIVESAY, and WILLIAM BARROW TURNER, as Associates.

The discussion upon the Paper No. 1,133, "On the Water Supply of Paris," was continued throughout the evening, to the exclusion of any other subject.

In pursuance of the notice on the card of the Meetings, it was proposed, and resolved unanimously, "That, in order to avoid holding a Meeting on the evening of Whit Tuesday, the Meeting be adjourned until the evening of the 29th inst.

CYCLOSCOPE.

After the Meeting, Mr. H. Temple Humphreys (Assoc. Inst. C.E.) exhibited and explained an instrument, called a Cycloscope, for setting out railway or other curves, without the aid of the transit theodolite, &c. Externally, it somewhat resembled a box sextant. It was composed of two essential parts only, viz.: two plane mirrors, one of which was silvered over the whole of its surface, and the other over one-half of its surface. By a law of physical optics, that called either combined or successive reflections, a series of images would be formed in the half-mirror, which were rendered available to set out any curve of any given radius, by applying the eye to an eye-hole in the back of the whole mirror, and at the same time setting the two mirrors at an angle to one another equal to the required tangential angle. Then the several successive reflected images of a ranging rod, for instance, were seen to lie upon the circumference of a mathematically true circle. The curve was then readily set out in the field, by simply placing other ranging rods in line with these several images. This could be done by looking through the unsilvered half of the half-mirror, and planting the rods opposite to and overlapping the successive reflections. No error could arise in the manipulation, and the whole process of setting out a true curve was shortened and simplified. After setting the mirrors to the requisite tangential angle, no further adjustment or support was needed, than could be afforded by the top of a ranging rod, placed at the commencement of the curve, and shifted occasionally to any stake on the curve, that the limits of distinct vision might require.

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[1] His Royal Highness has since been created Duke of Edinburgh.

May 29, 1866.

The Session was concluded by a Conversazione, at which the President received the Members of the Institution, and a numerous circle of distinguished visitors. The rooms were decorated with many choice works of art, and there was also exhibited an interesting collection of mechanical models.

APPENDIX TO VOL. XXV.

MEMOIRS.

Sir JOHN WILLIAM LUBBOCK, Bart., F.R.S., &c., the son of the well-known banker, Sir J. W. Lubbock, was born on the 26th of March, 1803. He received his education at Eton, and took his degree at Trinity College, Cambridge, in 1825; where his obtaining only the rank of first Senior Optime surprised all those who knew and could appreciate his mathematical attainments; the truth, however, was that he turned his particular attention to the branches of astromony in which he was afterwards distinguished, and having no special reason for seeking University honours, he was content to take what he could get on his own terms as to study. Throughout his life he applied himself to the lunar theory and the subjects connected with it. Out of the higher departments of astronomy, perhaps his most remarkable work was his excellent book, on "Probability," which he contributed to the "Library of Useful Knowledge," in conjunction with his friend Drinkwater (afterwards Drinkwater-Bethune.) This work was anonymous: a binder chose to letter it as "De Morgan on Probability," and Mr. De Morgan, in a letter to the "Times," stated that he could not in fifteen years, though using every opportunity, succeed in restoring the book to its true authors.

The early part of his life was devoted to the pursuit of science, particularly that of astronomy, in connection with which he investigated many questions respecting the action of the tides, the theory of the moon, and the perturbation of the planets, and the determination of the distance of a comet from the earth, and the elements of its orbit. He was by nature destined for a purely theoretical investigator, and science lost one of her most brilliant sons when the worldly affairs of the bank demanded the active co-operation of Mr. Lubbock. At the period of a great depression in the commercial world his talents were called into requisition, and he responded to the demands of his father and partners in a manner which conferred the highest honour upon his talents, his judgment, and his acquirements. When the time of trial was over, he returned to his more congenial pursuits, and occupied the position in the scientific world for which he was so eminently qualified. He was Treasurer to the Royal Society from 1830 to

1835, and again from 1838 to 1845. He was also for many years Vice-Chancellor of the University of London. By the Royal Society he was awarded the Royal Medal in 1834 for his Paper "On the Tides," and in 1848 the Astronomical Society gave him a testimonial for his "Researches on the Theory of Perturbation." His Bakerian Lecture "On the Tides at the Port of London," delivered in 1836, holds a very high place in that class of investigations. In 1848 he joined the Geological Society, where, during the brilliant portion of the career of that Society, he, with the other shining lights of those days, maintained the interest of the evening discussions. At the same time he found leisure to contribute Papers on interesting or on abstruse subjects to most of the principal scientific societies of eminence in the kingdom.

In addition to these communications he published several important works on astronomical and mathematical subjects; such as an "Elementary Treatise on the Computation of Eclipses and Occultations," "Remarks on the Classification of the different branches of Human Knowledge," "An Elementary Treatise on the Tides," "On the Heat of Vapour," and "On Astronomical Refractions," with several other minor works.

His communication to the Geological Society in 1848, "On Change of Climate, resulting from a Change in the Earth's Axis of Rotation," is deserving of special study.

He was elected an Honorary Member of the Institution of Civil Engineers March 5th, 1839, and he contributed to the Society, "A Theoretical Calculation of the Fuel saved by working Steam expansively."[1]

Sir John Lubbock united with his scientific attainments a good knowledge of business, and to this he added a character which obtained for him, in full measure, the respect of the world, and the regard of his friends. Social rank, wealth, commercial position, and scientific reputation did not give him the least disposition to overbear those with whom he came in contact. Many men, with union of several rights to presumption—if any rights there be—are prevented from claiming their rights by having nothing for which to fight. But Sir John Lubbock—especially when young—had very decided opinions, and, in a scientific discussion, would not unfrequently stand alone. But he had a genuine modesty of character which kept him far within what was due to others. He was keenly sensible to difference of opinion; but a scientific comrade used to say of him, that it made him angry with himself, and not with his opponents.

It cannot be affirmed that a man who dies in his sixty-third year has shortened his life by too wide a range of occupation; nevertheless, it may be feared that the double life which Sir John Lubbock led for some time produced that general debility under which he laboured for years before his death. At all events it may be said of him, as of many other men of energy, that had they tempered that energy, they would have lasted longer; but would they have been as useful?

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[1] *Vide* Minutes of Proceedings Inst. C E., vol. i. (1840), p. 3.

Sir John Lubbock died at High Elem, Farnborough, Kent, on the 20th June, 1865, in his sixty-third year, universally respected and regretted.

Mr. JOHN ISAAC HAWKINS, was born on the 14th March, 1772, at Taunton, Somersetshire, where his father exercised the calling of a watch and clockmaker. At an early age he left England for the United States of America, and entered the college at Jersey, Pennsylvania, as a student of medicine. His natural talent and inclination for mechanical pursuits, however, soon induced him to change his course of study, and to devote his attention to perfecting the mode of removing chemical and mechanical impurities from water, by filtration in contact with charcoal, &c. On his return to England he patented, and introduced to the public, a machine for taking likenesses in profile, from the size of life downwards. Combined with his talent for mechanical pursuits was that of a love for music. He had early in life mastered several musical instruments, and he now brought his ideas to bear upon their improvement, especially that of the pianoforte, which he commenced manufacturing under patents obtained by him. He also invented about this time, and some years afterwards manufactured, an instrument which he named the Claviole, or finger-keyed viol,[1] the scientific arrangements of which were so delicate and complete, that all the instruments usually composing a band were successfully imitated by one performer. His chief talent lay in inventing and improving upon the useful scientific contrivances for manufacturing processes, among which may be named the refining of sugar, by Howard's process, in the prosecution of which his acquaintance with the valuable properties of charcoal, as a purifying medium, was of great assistance, and he was induced to adapt it, with other combinations, for that purpose; and several years of his life were devoted to the erection and fitting up of sugar refineries, both at home and abroad.

During his foreign journeys, nothing that was new escaped his observation, and he was able to use the processes, or to quote their use most opportunely. For instance, in the course of a discussion at the Institution of Civil Engineers in 1844, when whole timber scaffolding was mentioned as a novel introduction, he stated, "That the scaffold used at Vienna, for the erection of any building of importance, was always constructed of whole timbers, secured together by 'dogs,' and that in 1827 he superintended the erection of an extensive sugar-house at Vienna, where such scaffolding was used."[1]

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[1] *Vide* "The Mechanics' Magazine," vol. xliii.

His co-operation was frequently sought for in works where ingenious contrivances were requisite; and he was associated with an attempt, made by Mr. Vesey in 1808, to drive a tunnel under the Thames, by sinking cylinders of brick, set in Roman cement, and placed in excavations made in the bed of the river. When the cylinders were deposited at the required depth, they were covered in, and their sides were opened, to effect continuous communication throughout. The tunnel was not, however, completed, owing to want of funds, and of unanimity in the Board of Directors.

His intimate acquaintance with physical science, as well as his correct knowledge of all the improvements in arts and manufactures which had taken place for many years, eminently qualified him for the profession of a patent agent and consulting Engineer, which he exercised for many years, bringing his varied experience to bear upon, and complete for practical purposes, the crude ideas of inventors.

His own improvements of useful instruments were very numerous, and among them may be mentioned the Pentagraph, an instrument for giving any number of copies of a letter, or other document, at the time of writing the original; this was somewhat generally used, until it was superseded by Wedgewood's carbonic manifold writer, and by the modern forms of copying-presses. The ever-pointed pencil, and the everlasting gold pen, are among his useful, though minute inventions; for the latter he took the residuum found after disolving platina, and, with the iridium, he skilfully pointed the gold pens.

He had for many years entertained the idea of returning to the United States, in order to perfect and to patent several new inventions; as he imagined that the expense of patents in Great Britain, at that time, pressed with undue severity upon inventors, since, unless they were prepared to incur a large expense for a problematical return, they could not exhibit their unpatented inventions, except at the risk of being deprived of them. On the other hand, he thought that the moderate charge to citizens of the United States of America, enabled a poor inventor to take out a patent there without the aid of a capitalist, and thus to convert his inventions into property, which he might take to market, and run no risk of losing his right. Being assisted by a few of the older members of the Institution of Civil Engineers, who knew him well and estimated his uprightness and simplicity of character, as well as the ingenuity of his mind, he carried this intention of emigration into effect in the autumn of 1848, and in a farewell letter he said, "The Creator has constituted me an inventor, and I consider every useful invention given me, as a commission from Him, in trust, for the benefit of mankind; and I should deem myself guilty of a breach of that trust, were I not to use every reasonable exertion to carry the same into effect, as long as it can afford me due support. Society is now enjoying many comforts and conveniences from my inventions, while I have great difficulty in procuring common necessaries."

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iii., p. 209.

Nothing was heard of him, after his arrival in the United States, until quite recently, when his death was reported to have occurred at Elizabeth Town, New Jersey, U.S., on the 28th of June, 1855. It is feared that his sanguine anticipations of the States being a land of promise for inventors were not realized, and that he might eventually have been really better appreciated, had he remained in England. He joined the Institution of Civil Engineers as a Member on the 27th April, 1824, was a constant attendant at the Meetings, taking part in the discussions, and always feeling a warm interest in the welfare of the society.

MR. JOHN LEWIS was born on the 20th of April, 1825, in the parish of Vaynor, county of Brecon. His parents were small but respectable farmers; and he received his education in a private school in the village of Cefn-Coed, which adjoins the now important town of Merthyr Tydvil. At an early age he exhibited a great aptitude for drawing, and was considerably in advance of those of his class in educational attainments. At seventeen years of age he had the good fortune to be placed in the drawing-office of the Dowlais Iron works, where he soon distinguished himself as a draughtsman, and obtained a good knowledge of Mechanical Engineering. He was afterwards removed to the mining-office of the same works, and was for a considerable time Surveyor of the extensive mining works of the Dowlais Company, under Mr. J. Dickinson, the Coal Viewer (now Inspector of Coal Mines for the Manchester District), and in that capacity Mr. Lewis acquired an extensive and varied knowledge of mining operations. He left the employ of the Dowlais Company in 1847, and undertook the superintendence of the erection of the Briton Ferry Iron works, Glamorganshire, which he completed to the satisfaction of the proprietors. In 1851 he commenced business on his own account, as a Mining Engineer and Surveyor, and from that period to the time of his death there were but few works of magnitude in

Glamorganshire and Breconshire with which he was not connected. He prepared the preliminary surveys of the Penarth Docks, and was also engaged upon the surveys of the Brecon and Merthyr Railway and its branches — in the preliminary surveys of the Rhymney Railway, and frequently by the Glamorganshire and Aberdare Canal Companies. He had likewise the management of the surveys of several collieries in the Merthyr, Rhondda, and Aberdare Coal Districts, including the extensive collieries of Mr. Crawshay, connected with the Cyfarthfa Iron works. In 1864 he developed the Bargoed Colliery, of which he was part proprietor. In 1851 he made the surveys for the supply of Weston-super-Mare with water, and in 1858 was engaged by the Merthyr Tydvil Local Board of Health to carry out the scheme of Mr. Hawksley (V.P. Inst. C.E.) for the supply of Merthyr with water. He did this to the entire satisfaction of the Board, and of the Chief Engineer; and, had he lived, he had intended to present an account of the works to the Institution.

He was elected a Member of the Institution of Civil Engineers in 1863, but attended few, if any, of its Meetings. Had his life been spared, he would have made a useful member, for one especial trait in his character was that of kindness, and a willingness to impart to others a share of the knowledge he possessed. In private life he was much esteemed for his unostentatiousness and amiability, and he died on the 10th of February, 1865, under very distressing circumstances, at the early age of only forty years, leaving a widow and two children to lament his loss.

MR. GEORGE MEREDITH was born in Dublin on the 8th of December, 1817; he was the second son of Mr. Benjamin Meredith, Civil Engineer, who successfully executed several important works in Ireland, and was engaged under Mr. George Stephenson in the construction of the Liverpool and Manchester Railway, his experience in the formation of public highways over marshy land in Ireland having enabled him to afford some useful suggestions in regard to the mode of passing over Chat Moss.

Mr. George Meredith, having received a good education, was for a time under his father's tuition, learning the theory of the profession, and at the age of sixteen was admitted into the office of the late Mr. J. U. Rastrick (M. Inst. C.E.), where he remained until the commencement of the construction of the London and Brighton Railway Company's lines in Sussex, when, in 1836, he was appointed Assistant Engineer under the late Mr. Statham (M. Inst. C.E.), and had charge of the construction of that portion of the line between Brighton and Shoreham, and of that from Brighton to Hayward's Heath, including the Clayton and the Patcham Tunnels.

Subsequently he was appointed Resident District Engineer on the Brighton, Lewes, and Hastings Railway, on which line he superintended and carried out several large works, including the curved viaduct from the Brighton Station, in the direction of Lewes; the tunnels at Rose Hill, Falmer, and Lewes, and a draw-bridge for carrying the railway over the River Ouse near Lewes. He afterwards took charge, for the same company, as Resident Engineer, of the Keymer Branch, from Hayward's Heath to Lewes. In 1847 he accepted the position of District Engineer, during the construction of the Nottingham and Grantham Railway, where, among other works, he executed the Gonerley Tunnel. He also designed and superintended the execution of the Grantham waterworks, reservoir, &c. In 1852, Mr. George Meredith went to Holland, as the representative of an English contractor, during the construction of the Antwerp and Rotterdam Railway, and on the completion of those works he was named Engineer to the Ottoman Railway Company, from Smyrna to Aidin. He next made a survey of a proposed line of railway from Constantinople to Adrianople, and he returned to England with the intention of taking measures to have this line carried out, when he was suddenly seized with an illness which terminated fatally on the 21st of October, 1864, in the forty-seventh year of his age.

Mr. Meredith was elected a Member of the Institution of Civil Engineers on the 6th of March, 1849, and was occasionally present at the meetings. He was of an unassuming and retiring disposition—of a frank and genial temperament—was much esteemed by his friends and acquaintance—and gave general satisfaction to all those by whom he was employed.

MR. JACOB PERKINS was born in 1766, in New England, United States of America. His direct ancestor is traced to have been born at Newent, in the county of Gloucester, in 1590, and he emigrated with his family to New England in 1631. Of the position of the family, as of the early education of Jacob Perkins, nothing positive is known; but it appears, that at an early age he exhibited considerable talent for mechanical invention, fostered doubtless by the examples around him, of men striving to supply every-day wants. Before he was twenty-one years of age, he had invented, and constructed, machinery for producing several articles of utility and luxury. Under the old Confederation, the State of Massachusetts established a Mint for striking copper coins, and Mr. Perkins was early employed by the Government to assist in doing this, and the old Massachusetts cents, stamped with the Indian and the Eagle, now only to be seen in collections of curiosities, were produced by him. At the age of twenty-four he invented a machine, which cut and headed nails at one operation, the title to which invention was only sustained by a lawsuit of seven years' duration. The nail-machine was first erected at Newburyport, his native town, and afterwards at Amesbury, on the river Merimac, where he erected a mill and a water-wheel, which, at that date and place, were considered wonderful efforts of mechanical boldness and ability, and the manufacture of nails is still carried on there.

One of the most important of his inventions was the engraving of bank-notes upon steel plates. Seventy-five years ago forgery of notes was carried on with an audacity and success which would be incredible at the present time. The ease with which the clumsy engravings of that day were imitated, was a temptation to every knave who could scratch copper; and counterfeits flooded the country to the serious detriment of trade. He at that time invented the stereotype check-plate, which no art of counterfeiting could match, and a security was thus given to bank paper which had never before been known. As this discovery has produced important and beneficial results, its origin merits some description. The stereotype check-plate was constructed in the following manner:—Small strips of wrought iron, about 3 inches long and ½ an inch square, were obtained. It was, however, at that time so difficult to procure iron, even of that small size, without a flaw, and yet sufficiently smooth to engrave upon, that it required a ton of iron bars to be cut up, in order to select a sufficient number of pieces to make a plate, only about 12 inches square, and ½ inch thick. These small pieces of iron were nicely fitted together, and fastened by means of wedges into a frame of brass, and after being "properly smoothed" on the surface, the plate was elaborately engraved with steel punches and graving-tools; by which means every portion of the plate was covered with small figures and letters. After this was done, all the pieces were removed from the brass frame, were enclosed in an iron box, and the box, filled up with finely-sifted animal carbon, being well luted with clay to prevent the possible admission of air, was then placed in a furnace, and kept red hot, for a few hours, after which it was taken out of the furnace, and the contents were thrown into a vessel of cold water. This process converted the iron into steel, and case-hardened all the pieces. To such an extent was this effected, that it became a matter of some difficulty and patience to replace all the pieces again into their original positions, particularly as the heating and cooling had somewhat changed their condition. This was, however, at length accomplished, and a perfect impression, suitable for the back of a bank-note, was produced. This engraving proved so difficult to imitate, that a law was passed, in the United States, making it imperative upon all banks to use the steel stereotype check-plate for printing the backs of the notes. The plate, from its extreme hardness, served the purpose of backing all the notes required for many years, without any deterioration of the engraving. Siderography,[1] or the art of engraving on steel, including another of his inventions, that of transferring or reproducing the original engraving on steel, by machinery, was subsequently extended throughout the United States.

In 1819, Mr. Perkins brought his bank-note machinery to this country, and explained the system to the Directors of the Bank of England, but he could never induce the authorities of that establishment to adopt it, while his patent was in force. It was, however, with certain modifications, afterwards introduced by the late Mr. John Oldham, of the Bank of Ireland, and the Bank of England notes were, for many years, printed from steel plates, engraved according to Mr. Perkins' system, without any recognition to the inventor, nor even the repayment of his expenses. The private banks, however, sustained him, and he was enabled by the aid of capitalists, who purchased an interest in the invention, to establish a manufactory for making and printing bank-notes, &c., which is now a flourishing concern, to the great advantage of the heirs of those who invested their capital in it.

In 1820, Mr. Perkins presented to the Society of Arts several valuable and well-matured inventions, which were published in the "Transactions" of that Society, and for which medals were awarded to him.[2] Soon after his arrival in London he made many scientific experiments, which were received with great interest by the Engineers and others of that day. His method of generating high-pressure steam, at a time when it was considered dangerous to exceed 5 lbs. to the square inch, was the wonder of the day. In 1824 he discharged bullets, under a pressure of 1,500 lbs. to the square inch, from a steam gun, which was exhibited at the Adelaide Gallery, Strand; and he also worked a steam engine expansively, under the same high pressure; from which latter experiment the working of high-pressure steam engines doubtless received an impulse. The Ordnance Select Committee, under the late Duke of Wellington, reported that the effect of steam at 1,500 lbs. upon the square inch, was equal to that of the best gunpowder, in discharging bullets of one ounce weight; but the Committee did not recommend any experiments to be made at the expense of the Government. Subsequently the French Government had a gun constructed by Mr. John Penn, of Greenwich, and sent it to Versailles, where an experiment was made in discharging leaden balls of three pounds weight; but in consequence of illness, Mr. Perkins could not superintend the trial, and it therefore was not attended with success.

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[1] *Vide* "Transactions of the Society of Arts," vol. xxxviii., p. 47. London, 1820.

[2] The large Silver Medal for his "Method of Warming and Ventilating Rooms, and of Ventilating the Holds of Ships;" ditto for his "Method of Fastening the Seams of Hose for Fire-engines, and of Connecting Two or more Lengths of Hose together;" the large Gold Medal for his "Improved Ship's Pump;" and the smaller Vulcan Gold Medal for a "Method of Drawing off Waste Water from Water-wheels."

The various experiments led Mr. Perkins and his friends into heavy expenses, but with all his great perseverance, he was unable to persuade Engineers to adopt his system of generating steam, although he showed that it was possible to construct boilers, which were perfectly safe from dangerous explosion,—an object still very desirable, as is testified by the great number of boiler explosions constantly occurring. Successive and harassing disappointments at length induced Mr. Perkins to retire from active pursuits, and the last fifteen years of his life were passed in retirement. He died in London in the year 1849, in the 84th year of his age, surrounded by his family, whom he left heir to his many discoveries, some of which have led to beneficial results, not only to his immediate descendants but to the public at large.

Mr. Jacob Perkins became a Member of the Institution of Civil Engineers in the year 1820, and was much esteemed by his contemporaries. He contributed a Paper, which was read at the Meeting on the 7th of February, 1837,[1] "On Locomotive Engines and the means of supplying them with Steam," in which he proposed that the steam should be generated, through the medium of steam surcharged with caloric, recommended the division of labour in the workshop, suggested that all the parts of different engines should be facsimiles, and that these should be manufactured at the places best adapted for their production. He possessed great inventive faculties, and had he lived only a few years later, when, by means of improved tools, his ingenious ideas could have been carried out, he would doubtless have attained great success.

Mr. FREDERICK WALTER SIMMS was born on the 24th of December, 1803, in the parish of St. Anne's, Blackfriars, London. He was the son of a manufacturer who, although at one time possessed of considerable means, was, during the latter years of his life, so much reduced by adverse speculations as to be unable to give any of his family much assistance at the outset of their various careers. Mr. F. W. Simms, therefore, having received a fair rudimentary education under such schoolmasters as those days afforded to the sons of persons of the middle classes, was obliged, in order to acquire the higher mathematical knowledge by which he was so much assisted in after-years, to attend the evening classes of an old master, who having served as a schoolmaster in the Navy, and being discharged after the long war, was glad to eke out his scanty means by hard work at all hours. After a start in a line of life which was ill suited both to his health and his tastes, and which was soon relinquished, Mr. F. W. Simms was articled to a surveyor, and quickly found himself, by a mere accident, placed upon the Irish Ordnance Survey, in which he was soon promoted to be the head of the Computing Department, a position which, although not a lucrative one, yet gave him the best opportunities for acquiring a practical knowledge of his profession with a rapidity and exactitude in taking field observations, to which he always acknowledged himself greatly indebted for his success in after-years. After passing a few years in Ireland, Mr. Simms applied for, and obtained, the post of Assistant Astronomer at the Royal Observatory, Greenwich, where he served under the late Mr. Pond, and having married upon the slender income his post afforded him, he was compelled to add to it by giving lessons in navigation to officers in the merchant service, and by surveying iron steam-ships for the adjustment of their compasses, according to a method just then introduced by the present Astronomer Royal, and taught by him to a few of his assistants, but which in a few years became generally known. This portion of a most laborious life was also marked by the production of several works which were published, but for which he received scarcely any pecuniary recompense; in such low light were literary and scientific attainments held in those days.[1] Being tired of hard continuous night work and only scanty reward, Mr. Simms became assistant to the late Mr. Henry Robinson Palmer (Vice-President, Inst. C.E.), on the South Eastern Railway and other works. He was afterwards Engineer to the Asphalte Company, in which capacity he visited Paris, to ascertain the French method of working that preparation, and to assist in its introduction into England. He was then employed under the late Sir William (at that time Mr.) Cubitt (Past-President, Inst. C.E) in laying out the line at present followed by the South Eastern Railway, the Company having been driven from the more direct route which the London, Chatham, and Dover Railway now takes, and being obliged to pay enormously to the refractory Kentish landlords for the circuitous line so selected; the struggle was continued year after year, and the attempts to wring assents from stubborn farmers, together with the difficulties overcome in the survey of the country to be passed through, furnished Mr. Simms with many amusing anecdotes for after-years. When the works of the South Eastern Railway were commenced, Mr. Simms was appointed Resident Engineer on the Pound Hill and Salt-wood Tunnel, by which he gained much of that practical experience and knowledge, afterwards embodied in his book on Tunnelling.[1] At that time he presented two communications to the Institution of Civil Engineers, one, the "Results of the application of horse-power to raising water from the working shafts at the Saltwood Tunnel, on the South Eastern Railway in 1842;" the other, "An account of the Brickmaking at the Blechingley Tunnel, during the winter of 1840 and the summer of 1841,"[2] for which he received a Telford Medal. His connection with the Company ceased after the completion of the Folkestone Hotel and Harbour Works.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1837), p. 20.

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[1] Including "A Treatise on Mathematical Instruments," 8vo., 1836; "A Treatise on Levelling," 8vo., 1837; and a "Treatise on Mathematical Drawing Instruments," 8vo., 1839; besides editing "The Public Works of Great Britain," folio, 1838.

Mr. Simms then became engaged in general practice; he laid out several lines long since completed, among others some of the French railways, and was rising rapidly during the few years which preceded the well-known panic of 1847, when the country seemed anxious to have all its railways made at once. At that time his friend the late General Sir Charles Pasley (Hon. M. Inst. C.E.) recommended him to the East India Company to fill the position of Consulting Engineer to the Government of India, an office which a taste for travelling, with the liberal and certain salary it afforded, induced him to accept, but which eventually became a loss, as ill health, induced by the fulfilment of duties involving much labour and exposure, obliged him at the early age of forty-nine to relinquish all further professional work, or ambition of advancement. Although he was sent to India to report to the Home Government on the capability of that country to receive the benefits of railway communication, Mr. Simms soon found that the title of Consulting Engineer to the Government meant a liability to be called upon to inspect the engineering works of India in general, and therefore he found himself sent out at all seasons to report upon the embankments of rivers, the sanitary state of towns, and the positions for new harbours, all which involved great exposure and much hardship, and drew from him a number of interesting reports and suggestions, as well as a survey of Calcutta on an extended scale, a work undertaken by him as Chairman of the sanitary commission of that city, for even twenty years ago the state of that town had attracted the attention of the authorities.

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[1] *Vide* "Practical Tunnelling, &c.," 4to., London, 1844. Ditto, 2nd edition, 4to, London, 1859.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. ii. (1843), pp. 112 and 145.

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[2] *Vide* Minutes of Proceedings Inst. C.E., vol. ii. (1843), pp. 112 and 145.

Unfortunately Mr. Simms, relying on an iron constitution, went to India at an age too advanced to bear the climate. He, therefore, fell a more ready prey to the mischief which hard work, ill health, and domestic troubles, wrought upon him, so that thoroughly shattered, he was obliged to leave India at the end of his five years' engagement, and to decline the offer of a reappointment. The thanks of the Indian Government, together with a compliment on the "energy and promptitude" with which all business had been passed through his office, were some solace for his many afflictions whilst resident in India.

On his return home, at the close of the year 1850, Mr. Simms had to struggle hard for life through a severe attack of inflammation of the liver, and on his recovery received the appointment of Consulting Engineer to the London, Chatham, and Dover Railway, then called the Mid-Kent Line: and so was once more upon old and well-known ground. But his nerve was gone: the slightest mental exertion was too much for him, and feeling incapable even of giving evidence before a Committee of the House of Commons in favour of that line, Mr. Simms resigned all professional work, and henceforth devoted himself entirely to scientific amusement. His name soon ceased to be publicly thought of, and he was only remembered by a few old acquaintances, by whom he was known as "South Eastern Simms." About eighteen months before his death, which occurred on the 20th of February, 1864, in the 61st year of his age, Mr. Simms was elected a Director of the East Indian Railway Company, and had the satisfaction to see the railway (now called the Chord Line) which he had recommended when in India, and had indicated as the best direction, adopted as a necessity; not merely because of its directness, but on account of the excellent coal-fields through which it must pass.

Mr. Simms was elected a Graduate of the Institution of Civil Engineers on the 13th of February, 1838, and was transferred to the class of Members on the 23rd of February, 1841. He was likewise a Fellow of the Royal Astronomical and of the Geological Societies, and to both he had contributed Papers, which received the favourable notice of those bodies.

MR. GEORGE ABERNETHY was born at Aberdeen, in the year 1815. He was first trained as a mechanical engineer at the establishment of Messrs. William Simpson and Co., in that city. Subsequently he was employed under Sir John Macneill (M. Inst. C.E.), in Ireland, and afterwards under Mr. Alexander Gibb (M. Inst. C.E.), as Resident Engineer on the Scottish North Eastern Railway. Since the year 1850 he was engaged under his brother, Mr. James Abernethy (M. Inst. C.E.), as General Assistant on various works, including the Swansea Docks, the Birkenhead Graving Docks and Ship-building Yards, Port Adelaide (Australia), and various minor undertakings. He died suddenly, at Natal, on the 4th of December, 1864, in the forty-ninth year of his age. He was elected an Associate of the Institution of Civil Engineers on the 6th of May, 1856, and when in London, never failed to avail himself of the opportunities afforded by the Institution.

MR. JOHN GEORGE APPOLD, F.R.S., &c., was born on the 14th of April, 1800. As a boy he evinced considerable talent for calculation and a decided turn for mechanical pursuits, which he was enabled to gratify by introducing improvements in the processes in use in his father's business—that of a fur skin-dyer, to which he eventually succeeded; and which, by his ingenuity and scientific improvements, he rendered very lucrative. In the early part of his career there were but rare opportunities for improvement by mixing with scientific men; but, as soon as it was practicable, Mr. Appold became a Member of the London Institution, where he enjoyed the advantages of the use of the Library, and of attending the evening meetings. In 1834 he was named one of the Auditors, and in 1844 he was elected one of the Managers; and henceforth he took great interest in the welfare of that Society. The excellent ventilation of the Library and of the Meeting Room are mainly due to his judicious instructions.

The processes of his own business being chiefly secret, it can only be inferred, that his ingenuity and scientific acquirements were aptly applied; and when great engineering works became more common, wherever there was any peculiar process, or any remarkable work, there Mr. Appold was to be found, and many eminent men have not hesitated to avow their obligations to his suggestions for a great part of their success on special occasions. He had peculiar facility for detecting the causes of error and of defects in machines, and he would watch indefatigably for any length of time to discover the cause of any peculiar action; his next employment being to devise some simple means of avoiding a recurrence of the error. By degrees, as he could afford to devote more time to the labour of his predilection—watching the mechanical progress of the period—the presence of Mr. Appold, on all experimental occasions, was naturally expected, and he thus made a very extensive acquaintance among the scientific and practical men of his day. Stimulated by the examples around him, he produced several very ingenious machines, the advantage of which he generally gave to the public—only a few of them being patented by

Messrs. Easton and Amos, who were usually intrusted with the execution of his projects.

His name will probably be most universally connected with the Appold Centrifugal Rotary Pump, which was so prominent a feature in the International Exhibitions of 1851 and 1862. He took great and unceasing interest in the laying of the Submarine Telegraph Cable to America, and the paying-out apparatus employed in the early attempts was mainly of his invention.

In addition to his own inventive powers, he possessed a peculiarly retentive memory, and the power of adapting parts of machines, or of contrivances to special circumstances. An instance of this occurred on the event of the unfortunate blowing up of the Outfall Works of the St. Germains' Sluice, Middle Level Drainage. As soon as Mr. Appold heard of the event, he started for the scene of the disaster, and watched for some time, with great interest, the attempts at closing the dam against the tide. That being partially accomplished, he heard the discussions as to the means to be adopted for relieving the fen country from the accumulating upland water. Here his good memory and his natural shrewdness became evident; and he ventured in his usually modest manner to suggest the use of syphons for carrying off the water in the manner so fully described in the Paper on the "Draining Syphon," for which the Gold Vulcan Medal of the Society of Arts was awarded in 1827 to the late Mr. R. Cowen, of Carlisle (Assoc. Inst. C.E.)[1] The syphons employed at the St. Germains' Sluice[2] were in importance and dimensions far beyond anything that was contemplated by Mr. Cowen, or had been used by Mr. Blackwell (M. Inst. C.E.) on the Avon Navigation; but the principles enunciated in the Paper so many years previously were of necessity adopted.

The useful scientific instruments invented, or improved by Mr. Appold, as well as the mechanical contrivances introduced by him, were very numerous; the principal among them—in addition to those which have been already mentioned—were, "The Hydrometer for Damping the Air to any specific degree of Moisture;" "A very delicate Thermometer;" "A system of Ventilation employed in the Hospital at Scutari;" "An Instrument for showing the Rise and Fall of Vessels at Sea;" "An Apparatus for Scraping and Cleaning the Water Pipes at Torquay," with many others which were adopted on the spur of the moment for special purposes.

His residence was full of his own ingenious inventions and adaptations. There everything that could be made so was automatic. The doors opened as the visitor approached them, and they closed after he had entered; water came unbidden into the basins; in the operation of lighting the gas the shutters were closed; a self-acting thermometer prevented the temperature rising or falling above or below certain fixed points; and the air supplied for ventilation was both washed to cool and screened to cleanse it from the otherwise inevitable soot. Even the gates of his stable-yard opened of themselves as he drove through, and closed again without slamming.

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[1] *Vide* "Transactions of the Society of Arts," 1827, vol. xlv., p. 113.
[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., p. 497.

All this ingenuity, combined with a genuine love of scientific pursuits was, however, as nothing when compared with the innate worth and honesty of Mr. Appold. Naturally of a simple, unobtrusive character, he was unbending in what he knew to be right: he was singularly unselfish; and his personal liberality was profuse. His means,—honestly earned by his own energies,—were very considerable, and he delighted to have his friends frequently around him, to dispense that hospitality in which he was so gracefully assisted by his amiable wife.

During the last few years of his life Mr. Appold suffered from an unsparing and painful complaint; and in the hope of obtaining relief, he made long journeys abroad, and tried all parts of his own country, but in vain; and his active and useful career terminated at Clifton on the 31st of August, 1865, in the sixty-fifth year of his age. He had amassed a large fortune, which, by his will, was very judiciously disposed of among his relatives and friends, he not having any family. All his workmen and servants were well remembered, and several bequests were made to scientific societies. Among others, he bequeathed One Thousand Pounds to the Institution of Civil Engineers, "for the general use and benefit of the Society."

Mr. Appold was elected a Fellow of the Royal Society in June, 1853, a distinction which he prized very highly. In May, 1850, he was elected an Associate of the Institution of Civil Engineers, served for one year on the Council, and as Auditor of Accounts on several occasions. He was a very constant attendant at the Meetings, frequently taking part in the discussions, and always contributing models and objects of interest for the Conversazione, and was on every occasion ready to assist any good object, pecuniarily or otherwise. Few men have deservedly enjoyed more fully than Mr. Appold the affectionate confidence and esteem of a large circle of friends, and his memory will long be cherished.

MR. JOHN STAINES ATKINSON, born on the 28th of June, 1822, was a son of Mr. John Atkinson, a builder, of London, who afterwards practised as an architect at Norwood. Young Atkinson acquired, in his father's office, a knowledge of the quality of materials, and the principles of construction, and was employed on buildings in progress of erection. He was afterwards articled to Messrs. Samuda Brothers, in whose works he obtained an extensive experience of Mechanical Engineering; and he continued in the service of that firm for some years after his apprenticeship had expired, and, among other work under them, he was appointed one of their assistants in constructing the Atmospheric Railways, on the London and Croydon, and the South Devon Lines. He was then engaged on other railway works in Wales, in the construction of iron bridges, and of machinery for crushing mineral ores. During the last three or four years of his life, in conjunction with Mr. J. R. Johnson, he was occupied in the production and improvement of automatic machines for the casting and dressing of printing type.

Mr. Atkinson was elected an Associate of the Institution of Civil Engineers in the year 1844, and he died after a short illness on the 11th of April, 1864, being then not quite 42 years of age. He was remarkably energetic, and very persevering in all that he undertook.

MR. WILLIAM HENRY RICHARDS CURLL, the fourth son of Mr. William Curll, of Braes, Dumfrieshire, was born at Edinburgh, on the 19th of November, 1828. He enjoyed the advantage of an excellent and classical education, first at one of the private schools of Edinburgh, and then for a course of years at the High School of that city. After leaving the High School, he devoted himself with much energy to the study of mathematics, under the guidance of a well-known and much-esteemed master, the late Mr. Walter Nichol; and at the same time he applied himself to improve his skill in drawing, for which he had early evinced a strong natural taste. In conformity with his inclinations, he was apprenticed to Messrs. Macallum and Dundas, Civil Engineers, Edinburgh, under whom he had great advantages for acquiring a thoroughly practical knowledge of his profession; and there is evidence that he availed himself of them, having been employed not only in the survey of landed estates, but also in connection with the Caledonian Railway, some parts of which were still being constructed. He remained for six years with Messrs. Macullum and Dundas, and then directed his thoughts to India, viewing it as a sphere where he would have ample scope for engineering, upon the railways which were in progress in that distant part of the British empire. He had obtained influential friendships in the course of his professional labours, and embarked for India, carrying with him the highest recommendations. On reaching Calcutta, he obtained an appointment on the East Indian Railway, in the Bengal district, where, with characteristic enthusiasm, he set to work, and, by assiduous attention and energetic efforts, he soon attracted the notice of those above him on the line. He was, accordingly, soon promoted—first as Resident Engineer, and subsequently as District Engineer, in the North-west Provinces, having under his charge the portion of the railway from Alighur to Delhi. This district embraced difficult points of engineering, and, in particular, the construction of two bridges—the one over the Hindun, twelve miles distant from Delhi, and the other over the Jumna, at the entrance into that city, where the river is of great breadth, and liable to heavy floods. It is impossible, in a sketch like this, to give any idea of the amount of careful calculation and constant watching, and skilful study and unwearied superintendence, which he expended in the construction of these works, whose thorough accomplishment he personally inspected at every step; and, while securing their complete soundness, guarded against any expenditure beyond what was strictly required.

His was a life of unwearied devotedness to the execution of his duties, and only varied by the awful and tragic events of the Indian mutiny; events in which he bore a large share, and of which the recollection was so painful, that he would scarcely ever refer to them. This dreadful outbreak interrupted his labours for some time; and his confinement and privations, while in the fort at Agra, broke down his hitherto robust health, and made it necessary for him to visit Europe; but he soon returned to the field of his duty with renewed energy, to carry on the works on whose completion his heart was set, and with which he had cherished the hope of having his name associated—a just ambition, doomed to be cruelly disappointed. Incessant labours like his, under an Indian sun, could not fail to undermine the strongest constitution. Unhappily, he disregarded the warnings of approaching illness; and it was not till he was laid prostrate by inflammation and fever, that he would listen to urgent counsel to return home.

He left India in the beginning of March, 1865, having taken a passage for England, with his wife and infant child, in the 'Malabar.' For a short time there was a prospect of his rallying; but the hot winds of the Indian Ocean were against him: his strength gradually failed; and he expired on the 10th of May, 1865, at the age of thirty-six, having been upwards of thirteen years in India.

If he had been spared, he would certainly have risen to high eminence in his profession; and all who knew him cannot fail to join in the regret that one so useful in his life, so full of kindness, and so animated by feelings of the highest and strictest honour, should have been thus prematurely taken away.

He was elected an Associate of the Institution of Civil Engineers on the 6th of December, 1859. Although precluded by the nature of his professional engagements from being present at the meetings, he had a strong sense of the utility of the Society, and took a lively interest in its prosperity.

MR. WILLIAM JOHNSON was born in 1823, at Kendal, in Westmorland. His father, who was a solicitor in that town, died when his third son, the subject of this notice, was six years old. The son received his education partly at Kendal, and partly at Wharton, a village in the north of Lancashire. Having early displayed a taste for mechanical pursuits, a situation was obtained for him at the cotton manufactory of Messrs. Ainsworth, at Preston. There he remained, studying the structure of the various machines within his reach, and improving his knowledge of practical mechanics, until the year 1843, when, in consequence of the representations of Messrs. Ainsworth as to his mechanical abilities, he was placed, through the instrumentality of Mr. Birley, with whose family he was connected on his mother's side, under the late Mr. J. G. Bodmer (M. Inst. C.E.), with whom he continued for about three years. He was, at that time, in the habit of contributing Articles to the mechanical periodicals of the day; and Mr. Buchanan, the editor of the "Glasgow Practical Mechanics' and Engineers' Magazine," offered him the sub-editorship of that journal. This appointment necessitated his removal to Glasgow in 1845. That periodical having been given up in 1848, Mr. Johnson, young as he was, had the enterprise to start the "Practical Mechanics' Journal," entirely on his own responsibility, which publication he carried on successfully for many years. Soon afterwards he undertook the business of a patent agent, and as this rapidly increased, and required more attention than he could give to it, he took into partnership his younger brother, Mr. John Henry Johnson (Assoc. Inst. C.E.). When it was found to be desirable that an office should be opened in London, the management of the latter was undertaken by the younger brother, whilst Mr. William Johnson remained at Glasgow, attending to his editorial duties, and managing the Scotch branch of the patent business. He was appointed Secretary to the Glasgow Committee for the Great Exhibition of 1851, in conjunction with the late Dr. Strang. Latterly his health gave way, and he withdrew in a great measure from his laborious duties. He died at Glasgow, on the 10th of June, 1864, leaving a widow and two young sons.

Mr. William Johnson was elected an Associate of the Institution of Civil Engineers in the year 1850. In engineering circles he was well known as being thoroughly acquainted with the details of machinery. He was remarkable for his power of rapidly grasping and comprehending the details of complicated mechanism. The "Practical Mechanics' Journal" contains many articles from his pen, describing or criticising the various inventions of the day. He edited the "Practical Draughtsman's Book of Industrial Design," a quarto volume, forming a course of mechanical engineering and architectural drawing, of which a second edition has already been published. He also contributed articles to several mechanical publications, his last work being that on Textile Machinery and Manufactures, and some other subjects, for the Scientific (or "Practical Mechanics' Journal") Record of the Great Exhibition of 1862.

MR. ROBERT RANSOME was born on the 27th of February, 1795. He was the second son of Mr. Robert Ransome who, in the year 1789, commenced, in Ipswich, an iron foundry, to which there became attached the manufactory of agricultural machinery, which has since attained a well-deserved and world-wide reputation. The younger Ransome was apprenticed to his father and his elder brother, in the year 1809, and after due education in the various handicrafts and processes carried on in the then humble factory, in which he had the assistance of Mr. (afterwards Sir) William Cubitt, at that time engaged at the works, he was admitted into partnership in the year 1818. During his apprenticeship, Mr. Ransome had sedulously employed his leisure in reading and self-improvement, and the habits thus acquired never forsook him; for, to the close of his life, he was always occupied; and the leisure which many love to spend in thought was by him employed in action—more frequently for the good of others than for his own gratification. Soon after joining his father's firm, the duties of traveller devolved upon him. In those days the task of the pioneer of improved agricultural machinery was no easy one; but by great perseverance and tact, Mr. Ransome succeeded in creating a large circle of friends, and in extending the business of the firm to a magnitude at that time quite unprecedented. After twenty years spent for the most part in this way, and partly also in the commercial management of the business, the firm having been joined by the late Mr. Charles May (M. Inst. C.E.), engaged largely in railway work, more particularly in the manufacture of the patent chairs invented by Mr. James Ransome, and the patent compressed wood fastenings invented by Mr. May. The commercial management at home then devolved entirely upon Mr. Ransome, and although the purely mechanical part of the business was ably performed by his partners and assistants, so that he had but little occasion to appear in public in connection with the undertakings of the firm, much of their success was due to his elasticity of spirit,—which always rose with difficulty or trial,—to his sterling conscientious integrity, and to his broad, liberal, and practical views. The value of these qualifications was nowhere more clearly manifested than in the internal economy of the works, in which, in 1849, after the decease of his elder brother, Mr. Ransome became the senior partner. The workmen, &c., then numbering more than a thousand, were gradually united by the force of his example, influencing them through their respective officers, in a spirit of friendly co-operation for one common object, the success of the firm: the disputes and differences of opinion which must arise at times in so large a body of men, were healed and harmonized, all willingly relying on the conscientiousness of their chief, and submitting cheerfully to his decision; for though strict indeed in his notions of right and wrong, they well knew him to be tender and gentle towards the failings of others, and ready to spare no personal labour for the comfort and happiness of all around him. Thus passed on many successful years, until Mr. Ransome, having virtually retired from the active conduct of the business, found himself at liberty to devote more time to the promotion of those public philanthropic movements in which he had always so much delighted. The prospect of a ripe old age seemed well assured; outward prosperity, excellent health, and a well-disciplined Christian mind, all were united to make the evening of life long and tranquil. But having undertaken, in the month of October, 1864, a trip on the Rhine with a valued friend, he entered so heartily into the enjoyment of the scenery that he could not be persuaded to leave the deck of the steamer on one piercingly cold day, and on arriving at St. Goar in the evening, he was struck with paralysis, from which he never rallied, and under which he finally sunk on the 6th of November, 1864, at the age of sixty-nine. His decease caused profound sorrow in Ipswich, and when his remains were borne to the grave, followed by the workmen of the Orwell Works, and by a large concourse of the inhabitants, there were few among the assembly who did not feel that they had lost a valued personal friend.

Mr. Ransome became an Associate of the Institution of Civil Engineers in 1841, and always felt great interest in the welfare and prosperity of the profession, entering with lively appreciation into the records of the great works undertaken by its members. He was a man of great and intense activity through life, and of extreme unselfishness; he was full of ardent sympathy with the difficulties and troubles that beset every one who strives to work out his own course in life; he was of unbending integrity, and many things looked on as conventionally correct he viewed as the reverse. No bond nor writing was more sacred to him than his simple word; nothing more dear to him than truthfulness. No time was too long, no trouble too great for him to take with any one whom he thought he could influence to a higher or a purer life. He laboured both by precept and example to do good in his generation, and he obtained his reward in the esteem and affection of all who knew him.

MR. ARTHUR WIGHTMAN was born at Old Brompton, Middlesex, on the 19th June, 1808, received his education at Tonbridge School, and at the age of seventeen obtained a commission as Ensign in the 49th Foot, and subsequently exchanged to the 21st Royal Welsh Fusiliers.

He left the army about the year 1831, and co-operated with his friend, Mr. Tyerman, of the firm of Hollingsworth, Tyerman, and Co., solicitors, in obtaining the sanction of Parliament for a railway between London and the East India Docks, at Blackwall. On the completion of the line, which was then called the Blackwall Railway, he was appointed Manager in 1840, and he devoted great care and attention to working the line, upon which the carriages were drawn by ropes, set in motion by stationary engines at both extremities, until the year 1849, when, feeling the inconvenience of the system, he was instrumental in changing it from rope-traction to locomotives, despite considerable opposition. In the year 1851 he assisted the London and North Western Railway to obtain their goods depôt at Haydon Square, in the Minories.

In the year 1854 he was appointed Manager of the London, Tilbury, and Southend Railway, under Messrs. Peto, Betts, and Brassey, the lessees, which position he held conjointly with the post of General Manager of the Blackwall Railway.

In each Parliamentary Session up to 1860, he was engaged in assisting the Great Northern Railway to establish a depôt in the City, and also in aiding to obtain branch lines for the Midland, the Great Eastern, and the London Docks, as well as in giving evidence of importance for other railway companies.

In the year 1863 he had a serious illness, from which he never recovered, and on the 8th of August, 1864, he died, sincerely regretted by all who knew him.

He joined the Institution of Civil Engineers as an Associate on the 1st March, 1853, and frequently attended the meetings when railway questions were under discussion.

COLONEL FREDERICK BLOM, who was elected a Member of the Institution of Civil Engineers April 10, 1832, and—

CAPTAIN GUSTAF LAGERHEIM, who joined the Institution of Civil Engineers, as a Member, May 23, 1820, were both distinguished officers in the Swedish service, and had been connected with Mr. Telford in his works in Sweden.

It is to be regretted that it has not been practicable to procure the materials from whence to draw up memoirs of these two distinguished Engineer Officers and Members of the Institution.

MR. EDWIN MARSHALL was a partner in the firm of Messrs. Brown, Marshall, and Co., of the Britannia Railway Carriage and Wagon Works, Birmingham, and took an active part in the management of that concern. He joined the Institution of Civil Engineers as an Associate, January 13, 1857, and died some time in the year 1865.

It is regretted that a memoir cannot be given of so worthy a man, but, on application for the necessary material, the reply received from Mr. J. E. Marshall was:—"I regret that I cannot comply with your request, asking for the particulars of the career of my late father (Edwin Marshall), as he in his life-time had the greatest objection to anything of the kind, and I have similar feelings."

⁂ The Memoirs of those deceased members which have been omitted, in consequence of the difficulty of procuring information from their friends, will, it is hoped, appear in the next Volume.

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